MANNED LUNAR EXPLORATION INVESTIGATIONS

SEMIANNUAL REPORT

July 1, 1964 to

January 1, 1965

January 1965

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature.

This report concerns work done on behalf of the National Aeronautics and Space Administration.

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

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INTRODUCTION AND RECOMMENDATIONS

Scope of Work

The purpose and scope of current work is to investigate, develop, and test methods for carrying out scientific investigations for Apollo and post-Apollo lunar exploration. This first six months has seen the establishment of five project areas of work involving geology, geophysics, surveying and photogrammetry, electronics support and investigations, and film documentation. Work has been concentrated in evaluating and documenting standard terrestrial operations involved in geological, geophysical and surveying field operations. This information will serve as a base for comparing and developing single and complexly sequenced mission operations, and provide basic time, motion, and information data for engineering design purposes and for mission operations analysis. The work has been concerned with operations that involve subjective as well as objective considerations of the physical environment, such as the nature of the data derived from geologic description and mapping operations. The time, motion and information data that have been reduced and analyzed to date are presented in this report. Evaluation of the data are continuing, and when completed, other reports will be prepared for this area of study.

Plans for the period of January - June, 1965, call for conducting missions operations sequences using instrumentation such as the lunar surveying staff and an exploration periscope in conjunction with a simple LEM mock-up. Depending on the status of investigations and availability of a suit, a simulated early Apollo mission under suited constraints is scheduled for late in the period. Surveying investigations involving the use of a theodolite-ranging laser system for control of extended traverses will be carried out early in the period. Recommendations as to the requirements for such a system will be forthcoming for traverses of a few miles to tens of miles. A mobile geological laboratory to be used in the development of roving missions is being fabricated. The vehicle is to be received late in February, to be followed by instrumentation for conducting surveying, geophysical and geological traverses. Instrumentation for the geophysical traverses will be concerned mainly with radiation detection and analysis.

Several sites for the testing and development of Apollo and roving

These included the Bonito Flow and cinder field, and the S. P. Crater flow and associated volcanic features in the San Franciscan volcanic field near Flagstaff; the Castle Butte diatreme complex and the Coliseum diatreme in the Navajo Reservation, east of Flagstaff; the Moses Rock diatreme of southeast Utah; and the Mono Craters area north of Bishop, California. During the next six months, work will continue at the Arizona sites. Additional work will be carried out at Meteor Crater, Arizona, and in the Barstow area, California. Much of the field testing, and scientific control of test sites will be for studies of Apollo-type missions.

Topical studies begun by project members are petrologic analysis (including sampling methods for general and specific scientific missions), photogrammetry and photogrammetric systems for geologic and topographic data, and imaging systems for the transmission of scientific data. Feasibility studies also are being made on data acquisition and surveillance systems for use in the field investigations. Some of these systems may be incorporated in a surveying staff and some in an exploration periscope to be used from either a stationary or mobile vehicle. Preliminary results of some of the topical studies are included in this report.

General support activities carried out by the projects include the establishment of horizontal and vertical surveying control at test sites, and the partial establishment of a Command, Data Reception, and Analysis (CDRA) facility for investigations of near-real time analysis of transmitted scientific data. A microwave link was established in the Flagstaff area so that test data can be transmitted from the test sites. The film documentation unit has obtained time and motion films of standard field operations in geology, geophysics and surveying which are available for operational analysis to design engineers and other interested persons in NASA.

Recommendations for Manned Lunar Exploration

Considerations derived from past experience, paper studies of mission profiles, and limited field operations and tests conducted to date, have resulted in the development of the following general concepts for carrying out manned lunar exploration. These form the framework of the missions testing and development program. They are considered to be preliminary and will be established, modified, or eliminated as the result of future missions operations testing. Recommendations relating to specific missions operations are contained in the reports for the individual projects.

Apollo Exploration

Exploration by man on the lunar surface, in light of anticipated mission constraints, should be highly automated, so that neither the man on the lunar surface nor the man in the LEM will be burdened with routine operations. Such operations commonly make up a significant part of the physical effort and the time expended during terrestrial field investigations.

Early Apollo missions in part will be directed to the study of

gations probably will be carried out within sight of the LEM. The surface astronaut should be free to observe and describe the details of his environment, and he should use his time and his field instruments so that his capabilities are utilized most effectively. He should be relieved, insofar as possible, of mechanical operations of determining and relaying positional and attitude data, or sensor information, relative to features described or instruments employed. A system carried by the astronaut, and one that holds the astronaut under surveillance from the LEM, should be employed to obtain and transmit continuous or nearly continuous positional and orientation information with no, or very little, use of the field investigator's time. This information, however, should be available to the investigator when needed to guide his observations. Imagery from both the astronaut and LEM exploration systems would provide objective records of both the setting and the details of the environment about the landing site. Sensors carried by the astronaut would supplement the imagery and verbal records with measurements of properties that might include bearing strengths, radiation, magnetism and electrical properties. During a traverse, the physical effort, other than that of making the traverse, should be directed toward carrying out operations dictated by the nature and by the emplacement or operation of instruments on the lunar surface. The astronaut should carry an imaging system that would record the details of the lunar surface, which would be supplemented by verbal description; the imaging system would also obtain records of the emplacement of the instruments.

Imagery obtained through a film photographic camera carried by the astronaut, as well as through an imaging system such as a vidicon camera, should be a part of the field exploration system. Stereoscopic imagery should be obtained by both the film and electronic systems, and be amenable to both photogrammetric and photometric analysis.

Visual data transmitted through a vidicon system, together with verbal information and positional information supplied by a tracking and ranging system, would permit the reconstruction on Earth, in near-real time, of much of the data transmitted by the astronaut. Near-real time evaluation conducted by the scientific panel would almost certainly result in much more efficient scientific exploration during normal missions than if no capability for real time evaluation and support is planned for during the conduct of a mission. The efficiency of such a team effort presumably would be optimized during pre-mission testing operations.

Sampling programs have yet to be developed. However, to obviate skewed sampling, it seems likely that a large number of small samples should be obtained during the traverses. Such sampling would provide a fair representation of a wide variety of lunar materials. A few special samples, selected for the preservation of texture, or large samples for special analysis, also should be collected. The collection of these probably would be made after some familiarity with the lunar surface is obtained.

A preliminary test conducted by the Geological Survey demonstrated the importance of surveillance of the surface astronaut from the vehi-

of the astronaut in the context of the environment, and permitted more ready understanding of the imagery and verbal information imparted by the surface astronaut. A surveillance imaging system located on the LEM could be monitored both by the LEM astronaut and by an Earth-based panel. The surveillance system could obtain basic scientific data, permit efficient extension of the field work by the LEM astronaut, could be of aid in directing the surface astronaut to points of interest that might not be readily apparent to him, or could be of help to the man on the surface by enabling him to relocate himself at some previously occupied station for special sampling purposes, instrument emplacement, or for re-examination of some critical relationship. Furthermore, if the LEM surveillance system automatically tracks the astronaut, the LEM astronaut could quickly and easily monitor the surface astronaut for safety as well as scientific purposes; there would be no need for a traverse and search procedure with periscope on the part of the LEM astronaut. Stadia reticles in the vidicon or periscope system would permit a rapid, accurate estimate of the range to the surface astronaut, and the system could be monitored quickly, without complex operational duties, by the LEM astronaut.

Post-Apollo Exploration

An astronaut surface-exploration system like that described above also would be of great use for individual excursions from a LEM/Shelter or mobile geological laboratory. The system would permit an optimum return of information that otherwise would not be obtained without close scrutiny of the lunar surface. An imaging system mounted on the mobile laboratory or small roving vehicle would permit panoramic surveillance of areas investigated. Stereoscopic imagery suitable for photogrammetric reduction and photometric analysis would be obtained through either horizontal- or vertical-base imagery. Here, as in Apollo exploration, as complete and as analytically reducible data as possible would be obtained within mission constraints.

Roving vehicle exploration traverses beyond the surveillance capability of a fixed base need the establishment of the location and elevation of data points and instrument stations along individual traverses to permit analysis and reduction of the geologic and geophysical data. Such control probably can be carried by back sights on targets by means of a ranging laser-theodolite surveying system carried on the roving vehicle. Such a system could also be used to locate data points, such as those for tracing key beds to define geologic structures, and those intersecting topographic prominences to establish surveying control laterally, and would obviate a visit to each feature. The ranging laser-theodolite system would have use for roving vehicle exploration of a few miles to hundreds of miles. This system also might have value as a signalling device to Earth for use in an emergency communications mode. During both limited and extended lunar vehicular traverses, the geologic activities might be considered as reconnaissance, with detailed exploration in small areas of special interest. Geophysical investigations, particularly seismic traverses, become more effective as the traverse lengths increase, with the longer

as might be effected by a ranging laser-theodolite system, is essential for evaluating the geophysical data.

Many samples could be collected during extended lunar traverses, or during extended lunar stay times at a fixed base in which there is limited mobility. Because sample return capability to Earth is fairly small, petrologic analysis of lunar materials will probably be required on the lunar surface to select the most valuable samples to be carried to Earth. In addition, data obtained on the samples discarded would form part of the permanent scientific record. The analysis equipment would be carried aboard a mobile laboratory, or be part of the instrument complex aboard a LEM/Shelter. Analysis equipment, such as a petrographic microscope and accessory equipment, X-ray diffractometer, X-ray spectrometer, gamma ray spectrometer, and other equipment for geochemical analysis would provide valuable information as to composition of the materials sampled. This information would aid in the direction of the scientific investigations on the lunar surface.

Much of the equipment that might be used in the exploration systems and concepts outlined above is within present design and manufacturing capabilities. The development of instruments and techniques into scientific missions remains to be done, then refined as the equipment, our knowledge of the Moon, and the specific scientific problems to be solved, become more sophisticated.

Preliminary Recommendations for LEM Periscope Design

Preliminary considerations suggest that a surveillance periscope on the LEM would be a highly useful scientific and operational instrument. It would have the following potential uses:

1. To obtain lunar panorama.
2. To increase safety factor for man on surface.
3. To obtain geologic and geomorphic description if LEM lands but astronaut cannot get out.
4. To obtain photography at different scales with self-developing film for annotation from LEM.
5. To plan exploration traverses before egress to surface.
6. To minimize familiarization reconnaissance for each succeeding excursion.
7. To obtain high resolution photographic imagery through periscope.

8. To transmit imagery that can be analyzed on Earth for point locations by monoscopic comparator or phototheodolite methods.

9. To obtain film and transmitted stereo-imagery for geologic and geomorphic interpretation on Earth.

10. To obtain vertical base stereo-imagery for photogrammetry analysis (See Swann and others, Astrogeology Technical Letter 3).

11. To obtain range, azimuth, and vertical angle information for mapping purposes.

12. To compile a map on Earth in near-real time from automatic data acquisition systems on periscope.

13. To provide a rugged back-up device that can be manually operated from the LEM in case of failure of any proposed

To fulfill these uses, the periscope should be designed to meet the following functional specifications:

1. Variable power magnifications of approximately 2X, 4X, and 8X, with 30°, 15°, and 7½° fields of view, respectively.

2. Stereo-viewing with approximately 30-inch base.

3. Tilt head, designed to tilt from +45° to -15° with a continual tilt capability.

4. Can be raised approximately 6 feet above LEM.

5. Rotatable 360° about its vertical axis, with azimuth scale relative to LEM.

6. Provision for automatic tracking of man on surface.

7. Telescopic alidade (stadia reticle) and/or optical range finder with capability of vertical angle determination.

   a) Required accuracies

      1) range: optimal, 1 foot in 1000 feet; minimal, 10 feet in 1000 feet.

      2) vertical and horizontal angles: optimal, 3.4' of arc; minimal, 34.0' of arc.

8. Eyepieces, and additional ports adaptable for mounting electronic imaging or film camera systems for stereo-photography.

LUNAR FIELD GEOLOGICAL METHODS

(H. H. Schmitt, Project Chief)

This report covers the principal activities of the Lunar Field Geological Methods project during the first half of fiscal year 1965. The project is involved primarily in time and information studies of field geological operations and in the development and testing of sequenced geological operations for early Apollo and extended Apollo scientific missions. In addition, project personnel have begun topical studies of petrological analysis, photography and photogrammetry, and lunar exploration instrumentation as these topics relate to the conduct of early and extended lunar missions.

The project activities are primarily field oriented, and consist

of potential use for lunar exploration. Potential mission operations are evaluated by comparing the time for an operation and the quantity and quality of data obtained with geological control data obtained by standard field methods. Statistical analysis of the data is employed where applicable.

The development of potential field geologic operations and missions for early Apollo will dominate the field investigations for the remainder of the fiscal year. Two shirt-sleeve tests of sequenced mission operations are tentatively scheduled for this period. The tests will employ the LEM mock-up and available test prototypes of Apollo instrumentation, will be conducted under various time constraints. If the progress of the projects mission development studies warrant it, space-suited operations will be tested during the latter part of the second test. The Apollo-oriented investigations also will be directly applicable to the conduct of extended Apollo and mobile laboratory missions. Additional project work that is specifically related to extended Apollo and mobile laboratory missions will be largely in the areas encompassed by the topical studies.

Geological Surveying

Simple surveying operations are commonly used during terrestrial geological investigations. Among these operations are pacing and the use of tapes, compasses, clinometers, hand levels, and open-sight and telescopic alidades. Most of these operations will probably have counterparts during some phases of manned lunar exploration. In addition, they involve relatively simple motions, the investigation of which will provide a basis for the analysis of similar motions under space-suited conditions.

As an early phase of its investigations, the project conducted time and information studies of several geological surveying operations utilizing various terrains and slopes near Flagstaff and the test subjects discussed in Appendix A. A detailed report of these studies now in preparation will include analysis of the following standard (shirt-sleeve) operations: walking speed; pace length; slope measurement by hand-held instruments; determination of relative elevation by hand leveling; grid layout for sampling or mapping purposes; and establishment of simple geologic survey nets.

Geological Description

General Statement

The general aspects of geological description during lunar exploration have been discussed by Swann and others (1964, p. 11). The Lunar Field Geological Methods project is investigating the methods of obtaining geological description and the role that such description can play under the various physical, equipment, and time constraints that are currently thought to be possible or probable during lunar exploration.

In addition to its inherent scientific value in interpretation of lunar features, geological description on the lunar surface may serve one or more of the following purposes:

1. Give context to data from returned imagery and samples
2. Give qualitative and quantitative data on topographic, structural, and textural features that cannot be adequately portrayed by the available imaging systems.
3. Give qualitative and quantitative data on lunar materials that cannot be readily sampled.
4. Give those data necessary to distinguish the units delineated and sampled during geologic mapping.
5. Give those data, in addition to transmitted imagery, that are necessary for the near-real time construction of a geologic map that is adequate to permit a monitoring astronaut or scientist to assist in the conduct of surface exploration.

6. Provide a back-up procedure for obtaining as much scientific data as possible should a failure of the imaging systems occur and/or the return of samples be impossible.

Description Guides

Descriptive data on geologic features within an area of detailed study during manned lunar exploration will be obtained largely by an astronaut on the surface. The three general methods (Swann and others, 1964, p. 13) by which the surface astronaut can obtain these data within the known missions constraints are:

1. Free or unrestricted description, possibly aided by brief check lists.
2. Description guided by verbal prompting from an astronaut inside a lunar spacecraft, or from Earth-based scientists.
3. A combination of these two methods in which the free description by the surface astronaut is monitored by the spacecraft astronaut or by Earth-based scientists, and amplified as required.

Description guides or check lists are necessary for the detailed investigation of the applicability of these methods. The guides can also be an aid in determining how geological description can fulfill the purposes previously outlined. Guides for various types of geological features will be useful in training astronauts in systematic free description and in the discrimination of geologic detail that does not unnecessarily duplicate the information obtainable from returned imagery and samples. If monitoring or prompting of the surface astronaut by a second party is found to be necessary during a mission, description guides will facilitate these operations after the astronauts have determined what features should be described.

Preliminary field description guides for some general types of geologic features are given in Appendix B. Guides for the following features are included: fresh rock, exposed rock, included rock fragments, minerals, layering, fractures, and folds.

Detailed description guides for more specific geological features found on Earth can be readily developed. As more information on the lunar surface becomes available through the unmanned probes and lunar orbiters, additional guides for features peculiar to the Moon can be developed and the previously developed guides modified if required.

description guides), when compared with the amount of available time on the lunar surface, will eventually necessitate the establishment of descriptive priorities. A determination of possible priorities will be one of the efforts of the Lunar Field Geological Methods project. It is probable, however, that the establishment of the final sequence of priorities will have to await the arrival of the astronauts on the Moon.

The items in upper case letters in the description guides in Appendix A are those that would probably be necessary to observe even if high resolution, black-and-white photographs (including orbiter photographs) of a given feature were returned. Very small size or subtle expression of feature, or a decrease in the resolution of the photographs, would increase the number of items to be observed.

Underlined items in the description guides would provide data not obtainable from a small, returned sample. Items indicated by (#) might, in some cases, be obtained from an oriented sample. If lunar textures are coarse, relative to the possible size of a sample, and the textures are too subtle to photograph, then those items indicated by (*) may need to be described.

In the optimum situation, in which a high quality photograph and a small sample are returned, the items in Appendix A that are both in upper case letters and underlined should be described, if they are present. These items, however, may not include those necessary to distinguish features delineated by geologic mapping during mission. The decision on what items represent the distinguishing characteristics of mappable features can be made with certainty only by the astronaut on the surface.

Descriptions of the various necessary items should be given by numerical values whenever possible. If there are significant variations in given dimensions, maximum, minimum and average values should be given. When it is reasonable to do so, dimensions should be referred to geometric forms, even if the form is only a gross approximation of the actual object.

A problem that sometimes arises when a description guide is employed is that details may be emphasized at the expense of the over-all picture, but this problem can be overcome by training and experience. An advantage of a description guide is that it is an aid in obtaining conciseness without sacrificing completeness. The compilation of a concise yet accurate geologic vocabulary may be an important later function of the project.

In geologic operations during which the observer is not the recorder, a major problem in systematic description is the oral labeling of rocks, rock units, fractures, folds and other geologic features. Unless an unequivocal system of labeling is used, the data may become mixed and later retrieval may be impossible. An effective data handling and analysis system will be sought to assure maximum return of usable scientific information.

Field Test Operations

for eight weeks on the quality and efficiency of methods for obtaining and recording geologic data. The tests utilized the subjects discussed in Appendix A as observers and recorders on test sites in northeastern Arizona and southeastern Utah. Because of the large amount of data obtained and the partially subjective nature of the data and their evaluation, analyses of the tests have not been completed. A separate report on these tests is scheduled for transmittal in February.

Geologic Mapping

(H. H. Schmitt and G. A. Swann)

General Statement

The purpose of terrestrial geologic mapping (see also Low, 1957; McKinstry, 1948, Part I) is to illustrate the spatial relationships of geologic features that are pertinent to a particular geologic problem or group of problems. Many problems in geology that bear on the sequence and mechanisms of geological events can be solved only after symbols designating the structural and stratigraphic elements have been compiled in the form of a map. The term "geologic mapping" implies that various features relating to the map are described by the observer in some form of notes, supplemented by samples and sketches or photographs of the materials described. The full value of the description and sampling is realized only when the data and samples obtained are placed in the context of the geometry of the geologic features they represent.

The map scale, or the ratio of map distance to actual distance, is primarily a function of five factors:

1. The amount of detail required for the particular objectives of the investigation.
2. The geometric complexity of the geologic units.
3. The size of the smallest features pertinent to the geologic interpretation of the distribution of the units.
4. The accuracy of available or obtainable surveying data.
5. The time and manpower available to complete the investigations.

Geologic mapping of the lunar surface will serve the same basic purpose as terrestrial geologic mapping, and its scale will be governed by the same factors. The delineation of particular objectives of the investigations, the complexity of geometry, and the size of pertinent features will be partly elucidated by the results of the manned and unmanned lunar orbiters, the unmanned exploration programs, and the early manned landings. As a result of our knowledge of terrestrial geologic mapping, lunar telescopic mapping, the sizes of land forms shown on the Ranger VII photographs, and the restrictions the lunar environment imposes on man, some preliminary estimates can be made of the map scales that might be employed during early lunar exploration. Any maps made during the first few Apollo missions will probably cover areas extending less than 500 meters from the spacecraft. They will

of 1:500 or 1:1000. At these scales, features as small as 2 meters across can be easily portrayed on a map. The astronaut's descriptions and the photographs taken from the imaging system available to the astronaut will aid in the description and post-mission mapping of features smaller than 2 meters.

During LEM/Shelter and mobile laboratory missions, with relatively large amounts of time and mobility available for surface exploration, and with more knowledge concerning what observations should be pertinent to lunar geologic problems, geologic maps of 1:500 to 1:25,000 scale will probably be compiled that cover large areas. More attention also will be paid to details that are determined to be important to the solution of specific problems. These detailed maps should be tied together by reconnaissance maps obtained during the vehicular traverses at scales on the order of 1:100,000 to 1:250,000, so that problems related to the regional distribution of features and materials can be examined.

The two basic types of geologic mapping, that is, on-site mapping and remote mapping, will be utilized during manned lunar exploration. Remote, photographic and telescopic lunar mapping at a scale of 1:1,000,000 has been begun by the U. S. Geological Survey, and such mapping in progressively greater detail will continue up to and during manned exploration. On-site mapping will begin with man's arrival on the surface.

The varieties of remote geologic mapping techniques that probably are applicable to manned exploration are

1. Mapping on vertical photographs obtained from lunar orbiters.
2. Mapping on photographs taken from or near a spacecraft on the surface.
3. Mapping controlled by the remote determination of range and bearing.

Several general types of on-site mapping methods could probably be of use during various phases of manned exploration. They are

1. Mapping on vertical photographs obtained from lunar orbiters.
2. Mapping controlled by automatic tracking of an astronaut on foot.
3. Mapping controlled by photogrammetry using photographs taken on the lunar surface.

4. Mapping controlled by manually determined range and bearing.

5. Mapping performed from a roving vehicle and controlled by the automatic tracking of the vehicle.

Until the final base maps are obtained, mission development studies directed toward geologic mapping will have to cover all reasonable possibilities. However, no matter what base maps are available, some geological surveying will be necessary during the conduct of mapping operations. If an automatic range, bearing and vertical angle-measuring device can be developed for lunar exploration, many of the mechanical problems of geological surveying will be solved. In the event this type of device is not available or fails to operate properly, or if areas not visible from the LEM or mobile laboratory are to be explored, simple, manual methods of locating and plotting data points must be used.

determining the character of lunar geologic mapping. Marked advances in spacesuit design are being made; however, until data on the micrometeoroid and radiation fluxes on the lunar surface are obtained, no definite predictions on the final design and mobility of the suit can be made.

One objective of the Lunar Field Geological Methods project is the field testing of mapping techniques that are of potential use to man on the lunar surface. The field tests will perform the following functions:

1. Test the quality of methods that may be applicable to determining the spatial relationships of geologic features

on the Moon against control maps compiled by methods of known precision.

2. Test the quality of descriptive and sampling techniques applicable to lunar exploration against techniques known to be adequate for various geological purposes on Earth.
3. Evaluate the interpretive results obtained from prototype mapping methods with those obtained by methods commonly used in terrestrial geologic exploration.
4. Suggest new or modified methods and equipment that should be developed and tested.

Preset Grid Mapping

(H. H. Schmitt and W. J. Rozema)

The use of a preset grid or survey net for geologic mapping during lunar exploration is probably limited in its potential usefulness to roving vehicle or mobile laboratory exploration. Unless a rapid method for setting out a widely spaced grid is developed, there would appear to be little use for this mapping method during early Apollo missions, as a prohibitive amount of time is required for a man or pair of men to lay out a large mapping grid. With the aid of a vehicle and automatic bearing and distance measurement, however, a grid could be easily established. Once a grid is available, it provides means of controlling a relatively rapid method for the detailed mapping of complexly interrelated features.

Field test operations and results.--A test of geologic mapping at a scale of 1:1200 and controlled by a preset grid on a 15.2 m (50 ft.)

interval was conducted on the Moses Rock diatreme in southeastern Utah. An area 121.8 m (400 ft.) by 152.2 m (500 ft.) was mapped by persons whose training ranged from 6 semester hours in classroom geology to 7 years in post-graduate geological research, and whose field experience ranged from 1.0 months to 7 years in field mapping (see Appendix A).

The Moses Rock diatreme is currently being investigated in detail by T. R. McGetchin of the Branch of Astrogeology. It consists of a composite, irregular dike-like mass of multilithic serpentine breccia that intrudes layered sandstones, siltstones, and shales of the Permian Cutler Formation. The diatreme probably represents a deeply exposed portion of a volcanic neck. The heterogeneous nature of the body may be analogous in many respects to some volcanic materials or impact ejecta on the lunar surface.

ducted on the description of outcrops within the map area, so that each test subject had some, but not complete, familiarity with the rock units. The subjects were instructed that there was no time limit on the test and that each was to do what he considered to be an adequate job of mapping the geology of the test area. Each subject was made aware of the fact that in most parts of the area bedrock could be exposed by scraping away the three to ten centimeter-thick cover of windblown sand. The maps were drawn on grid paper marked in 0.58 cm (0.2 in.) intervals. A Brunton compass was used for measurements of plane orientations.

Figures 1 through 10 in Appendix C are copies of the maps produced by the various test subjects during the test. No effort has been made to improve the quality of the maps except to make them legible. The explanations for each map have been edited for clarity. Table 1 gives the data obtained by the evaluation of the maps. The experience levels of each test subject are given in Appendix A. For simplicity, the total geological experience of a test subject outside his undergraduate classroom, including undergraduate field mapping, is referred to below as his "experience level."

For the evaluations of quality given in table 1, the map shown in text figure 1 was used as the control map. The control map shows most of the detail that could be recorded at the scale employed. In the evaluation of the quality of the test maps, any data on a test map that was not on the control map was assumed to be correct. Table 2 gives the details on the control map that are of probable pertinence in determining the origins of the rocks in the area.

Text figure 2 is a scatter diagram showing the correlation between geologic unit areas delineated on the test maps and mapping time, and the correlation between the total number of potentially useful details mapped by each test subject (number of areas delineated plus number of orientation measurements) and mapping time. Linear correlation coefficients have been calculated for those data points in figure 1 which represent test subjects with experience levels of less than 6.6 months. For the correlation between unit areas delineated and mapping time, the coefficient is 0.46, and for the correlation between total details mapped and mapping time, the coefficient is 0.56. The values suggest very little correlation between mapping time and quantity of detail. However,

Table 1.--Preset grid mapping (1:1200 scale)

Data obtained from preset grid mapping test (15.2 m interval). Test maps are given in Appendix C. Figure 1 is the control map used for the evaluation of quality.

ubject	or test in hours 1	. of geologic units distinguished 2	. of geologic unit areas delineated 3	. of unit areas delineated correctly eference to control map 4	of unit areas delineated correctly ber of unit areas delineated 5	. of layer orientations measured 6	. of layer orientations measured tly with reference to control map 7	. of fracture orientations measured 8	. of fracture orientations measured tly with reference to control map 9	. of contact orientations measured 10	of potentially useful details map- um of figures in columns 3, 6, 8, 11) 11	of details mapped correctly (sum of s in columns 4, 7, 9, and 11) 12	of details mapped correctly to number of details mapped 13	. of details mapped that are of le pertinence to determining the s of the rocks in the area (see 2) 14
A	7.4	7	58	52.5	0.91	8	5.25	0	-	0	66	57.75	0.88	10
C	9.8	9	57	45.5	0.80	12	7.5	8	7	0	77	60.0	0.78	7.75
E	6.5	12	41	29.0	0.71	21	19.5	6	3	0	68	51.5	0.76	4.75
F	4.8	7	40	24.0	0.60	11	7.5	7	3.5	0	58	35.0	0.60	4
G	4.5	7	32	21.0	0.66	7	7	14	14	0	53	42.0	0.79	4.5
H	2.8	7	31	18.5	0.60	6	4.5	0	-	0	37	23.0	0.62	4
I	3.7	7	36	26.5	0.74	7	4.5	2	0.5	0	45	31.5	0.70	5.5
J[a]	13	17	142	-	1.00	22	-	45	-	2	211	-	1.00	19
K	6.5	13	86	77	0.90	34	31.5	43	43	1	164	150.5	0.92	12
L	6.5	11	113	94.5	0.84	13	9.5	0	-	0	126	104	0.83	5
M	6	7	32	28	0.88	15.5	14.5	2	2	0	127.5[b]	122.5[c]	0.96	7.5

a) Map used as control map

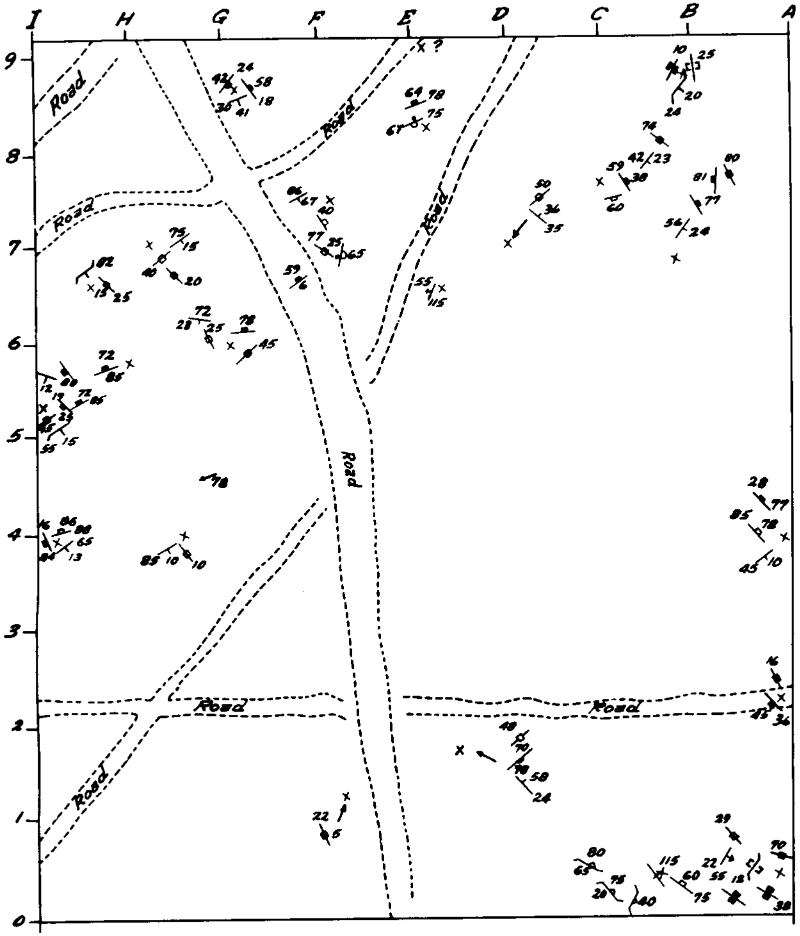
b) Includes 78 details recorded in notebook

c) 78 details recorded in notebook assumed to be correct

Table 2.--Preset grid mapping (1:1200 scale)

Map details on control map (text figure 1) that are of probable pertinence to the determination of the origins of the rocks in the area.

1. Layered nature of rocks surrounding combined breccia units (gb, rb, xb, xrb and gby of control map).
2. Wide variety of rock units in rock surrounding combined breccia unit.
3. Determination of stratigraphic sequence in layered rocks surrounding breccia unit.
4. Combined breccia unit cross-cuts layered rocks.
5. Layered units can be correlated across breccia unit.
6. Unit rb in combined breccia unit contains fragments of the surrounding rock units.
7. In the northern portion of the map area, a large fragment composed in part of sl is overturned.
8. Distinction of more than one breccia unit.
9. Distinction of xb, xrb, or gby as distinct breccia units.
10. Dike-like character of breccia unit composed of xb and rb in western portion of map area.
11. Presence of rb between xb and rocks surrounding the dike of xb and rb.
12. Unit xb lenses out at bend in dike of xb and rb.
13. The apparent movement of the west wall of the dike of xb and rb is right lateral.
14. The apparent movement of the east wall of the dike of xb and rb is left lateral.
15. The west wall of the dike of xb and rb has a measurable, nearly vertical orientation.
16. The surface trace of the dike of xb and rb is essentially independent of topography.
17. A set of fractures with grey-green walls in otherwise red brown rocks subparallels the dike of xb and rb.
18. Unit gby follows the eastern contact of the combined breccia unit.
19. A small fault can be delineated in the northwestern portion of the map area.



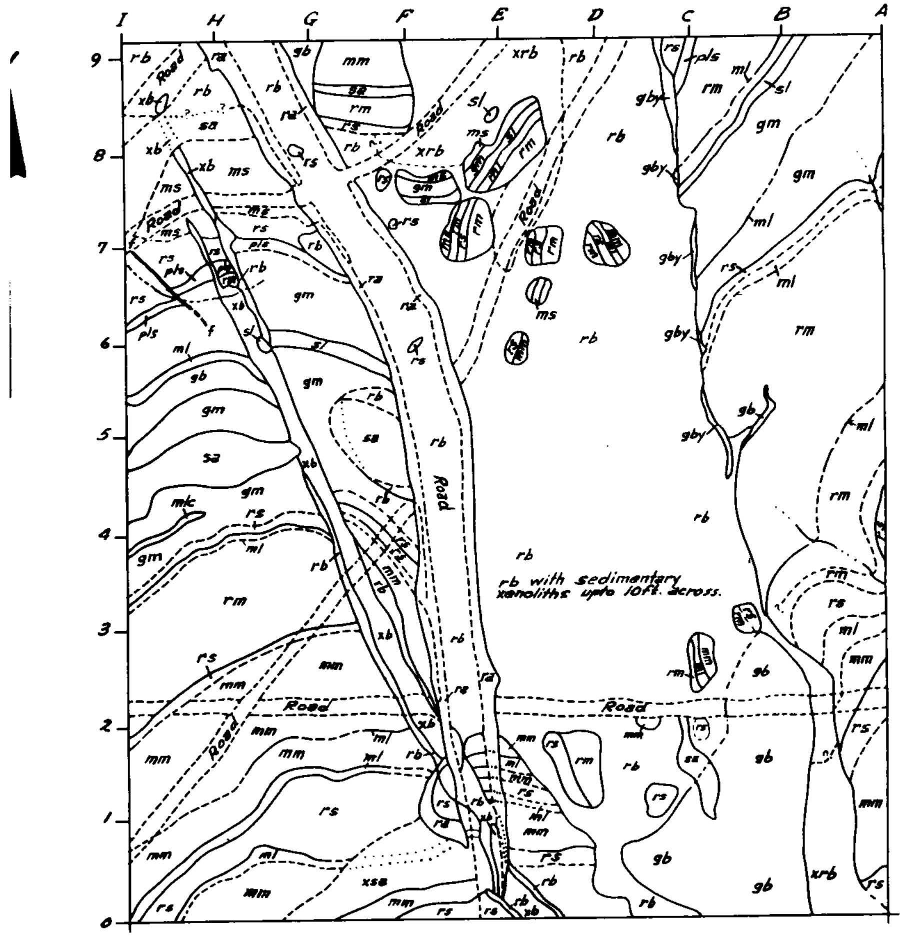


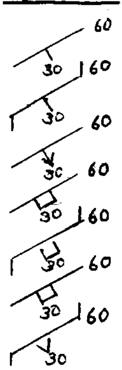
Figure 1.--Control map. Moses Diatreme, San Juan County, Utah.
Geologic Map 115 Test Subject J
Mappi: me 13 hours
Scale: 1:1200 (1" ')
Base: Grid points 0' interval

Explanation for Figure 1

Units

sa	light red brown, sandy aluvium
xsa	sa with pebble to cobble size xenolith fragments
ra	road fill or bank
rs	moderate red-brown, calcareous sandstone
mm	moderate maroon, light green-gray, and moderate red-brown calcareous mudstones and siltstones
ms	moderate maroon to red-brown sandstones and siltstones
gm	light green-gray mudstone to siltstone
rm	moderate red-brown mudstone, sandstone and siltstone, thinly interbedded
sl	light red-brown sandy limestone or limey sandstone. Lower few inches light green-gray
ml	moderate maroon limestone that weathers light greenish brown
mlc	ml conglomerate
pls	pink, thickly bedded, silty to clayey limestone or silty calcareous claystone
gb	green micro-breccia with pebble size zenoliths
rb	boulder sized fragments of sa and ms in matrix of gb
xb	green micro-breccia with pebble to cobble size xenoliths
xrb	rb with pebble to cobble size xenoliths
gby	yellow-green gb

Symbols



unplotted dip and strike of layering
unplotted, approximate dip and strike of layering
unplotted dip and strike of layering showing tops
unplotted dip and strike of joints
unplotted, approximate dip and strike of joints
unplotted, dip and strike of joint with light green-gray walls
unplotted, approximate dip and strike of oriented xenoliths

—·····—	course of intermittent stream
———	contact, observed within 3 feet
----?--	approximate or inferred contact, queried where probable
·······?··	concealed contact, queried where probable

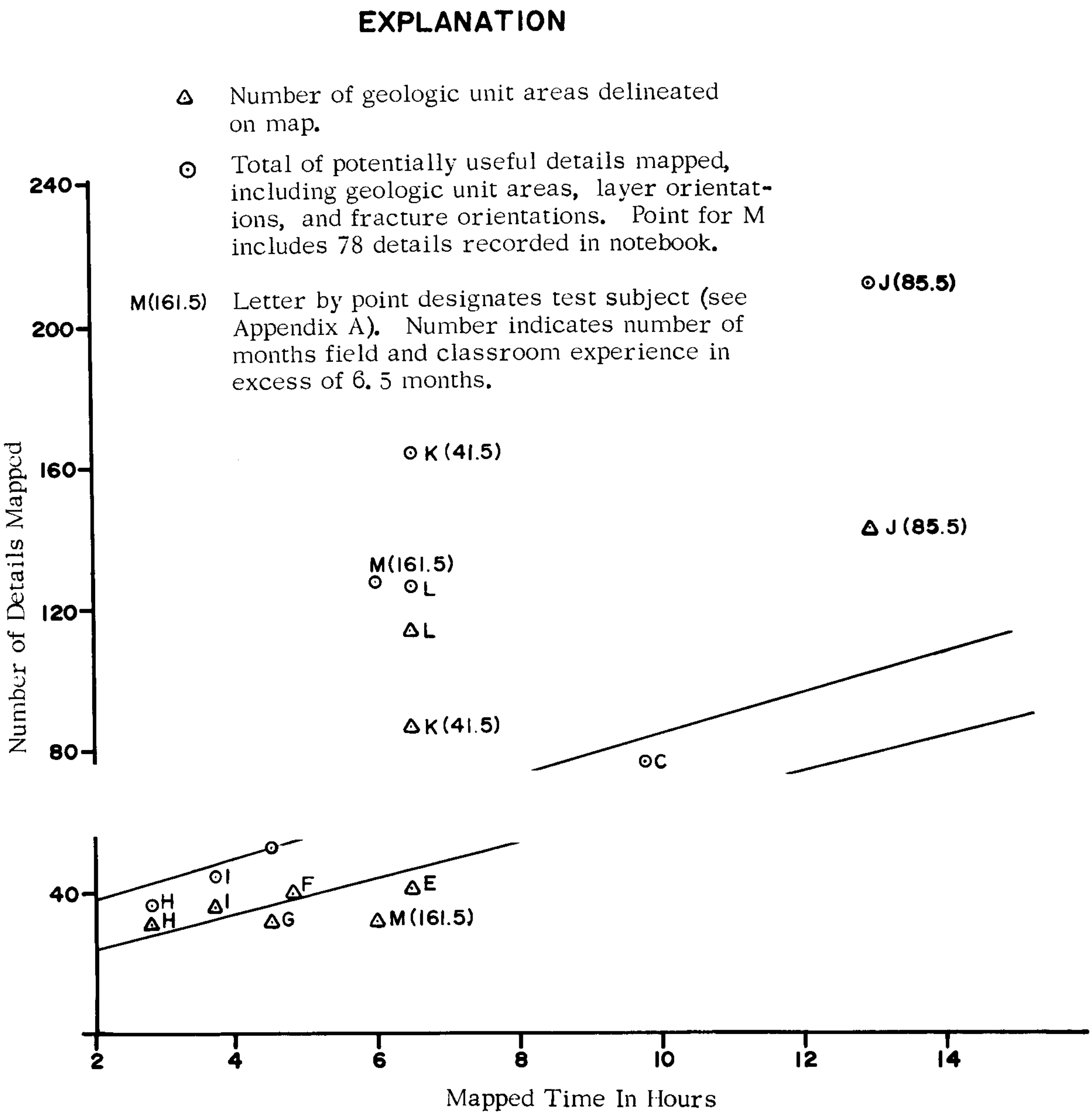


Figure 2.--Geologic mapping controlled by preset grid (1:1200 scale). Scatter diagram showing correlation between the quantity of map detail and mapping time.

when coefficients are calculated so that subject L is excluded, they increase to 0.87 and 0.95, respectively. Although subject L was exceptionally efficient at the mechanical operations of mapping, it will be noted below that the quality of his mapping is commensurate with his experience level of 1.0 months.

Figure 3 is a scatter diagram showing the overall mapping quality of the test maps, that is, the correlation between mapping time and the ratio of potentially useful details mapped correctly to the total number of details mapped. For test subjects with experience levels of less than 6.6 months, the linear correlation coefficient for correlation between quality and mapping time is 0.66, suggesting a slightly better correlation between experience level and quality per unit time, than between experience level and quantity per unit time.

The correlation between number of pertinent details mapped by the test subjects and mapping time is shown as a scatter diagram in figure 4. For test subjects with experience levels of less than 6.6 months, the linear correlation coefficient for this correlation is 0.67. This value, although low, suggests that for a given experience level the pertinency of mapping may be a function of time, as might be expected. Figure 4, as well as figures 2 and 3, indicates that both the quantity of details mapped and the quality of the mapping per given mapping time is much greater for test subjects with experience levels greater than 6.6 months than for other test subjects.

<u>Conclusions</u>.--It should be recognized that the evaluation of the quality of various observations is in part subjective, as the control

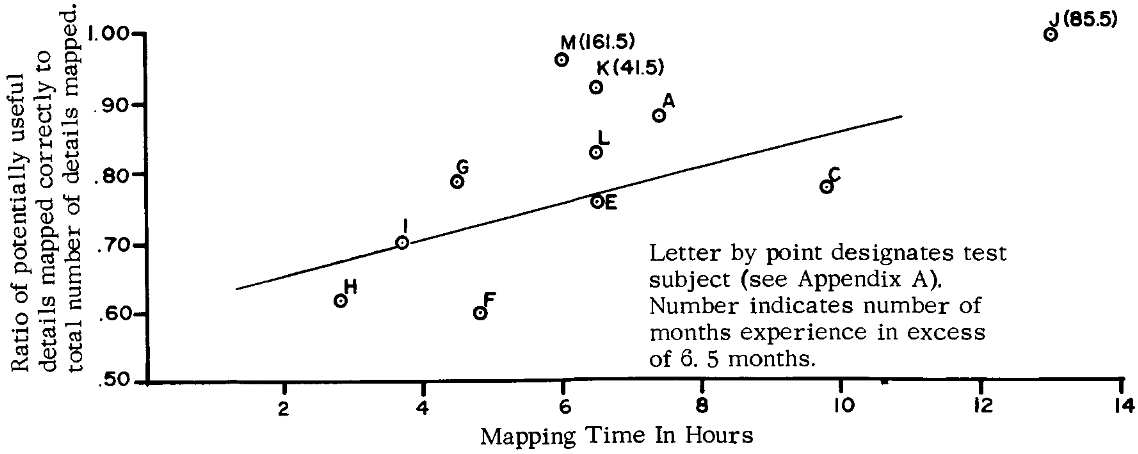


Figure 3.--Geologic mapping controlled by preset grid (1:1200 scale). Scatter diagram showing correlation between the quality of map detail and mapping time.

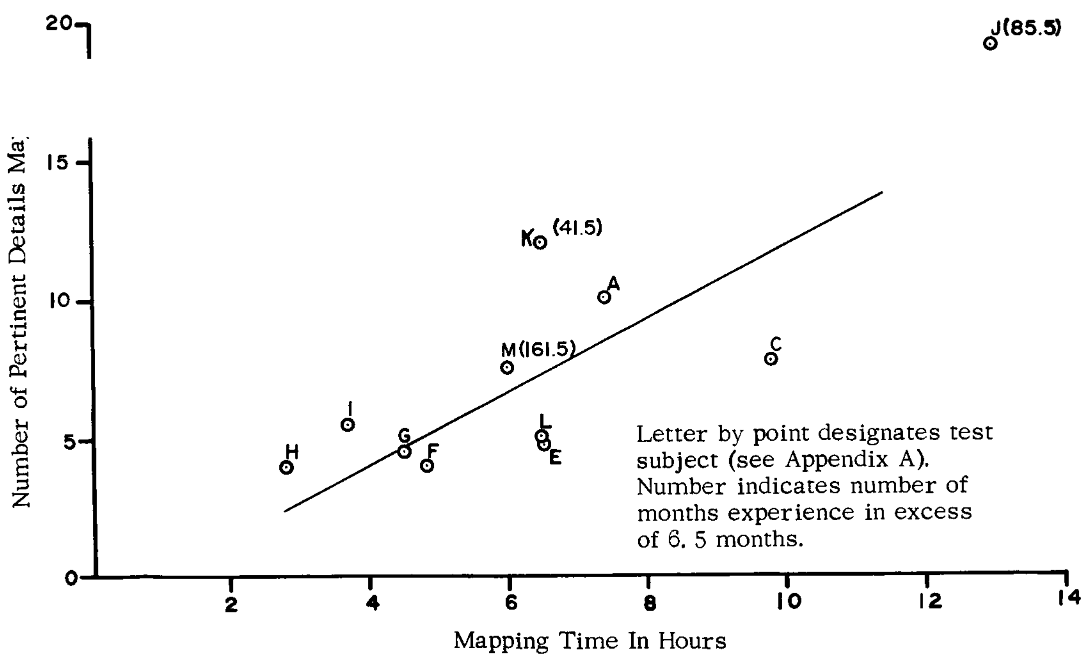


Figure 4.--Geologic mapping controlled by preset grid (1:1200 scale). Scatter diagram showing the pertinency of mapping as a function of mapping time (refer to table 2 for listing of pertinent details in test area).

map is based on partially subjective interpretations, resulting from the incomplete exposure of bedrock. With this limitation in mind, several general conclusions can be based on the distribution of data points in figures 2, 3, and 4.

1. For an experience level of less than about six months, figure 2 indicates that the number of potentially useful observations obtained increases roughly linearly with time (linear correlation coefficients of 0.87 and 0.95, neglecting point for subject L).
2. Although the data do not warrant any precise quantitative evaluation, figure 2 also indicates that test subjects having the relatively high experience levels obtained roughly twice as many potentially useful observations during a given time as were obtained by personnel with experience of less than 6.6 months.
3. Figure 3 shows that the quality of observations is significantly greater for experience levels of more than about six months than for experience levels less than this figure. The variability of quality among the test subjects with similar experience levels is probably a reflection of the variation in overall ability, types of experience, the partially subjective nature of the evaluation and motivation on the day of the test.
4. Figure 4 indicates that for all test subjects except subject K and J, the mapping of pertinent details

increases roughly linearly with time (linear correlation coefficient of 0.67). Subject K had had previous experience mapping in the vicinity of the map area and subject J's map was used to evaluate the others.

The results of the test suggest the need for at least six months of astronaut training in geologic mapping in addition to field trips and classroom work in geology. The test also suggests that if a geologically trained astronaut decides to solve a particular set of problems by the detailed mapping of an unfamiliar lunar area of the approximate size and complexity of the test area, he must allot no less than six man-hours if he is to obtain enough pertinent details to closely determine the geologic history of the rocks.

As a side light to the test, the detail shown in text figure 1

dust layer need not interfere with mapping bedrock geology if the layer is not too thick to scrape away at selected localities. The dust layer in the test area was 3 to 10 cm thick in most low areas. The examination of bedrock could be accomplished by scraping with a geologist's pick. Because of the possible restrictions on bending or kneeling in a spacesuit, a scraper on the end of a surveying staff may be more useful for this purpose than a pick on the lunar surface. By adjusting its orientation, such a scraper could also be used as a sample scoop.

Traverse Mapping

(G. A. Swann and H. H. Schmitt)

It is very likely that some form of geologic traverse mapping will be employed by the astronauts during part of every lunar mission. Basically, geologic traverse mapping means that a man on foot occupies, surveys, describes, and samples successive points along an irregular and only partially planned path. The results of a field test of one type of potentially useful traverse mapping for lunar exploration are reported below.

Field test operations and results.--A field test of one hour and 50 minutes duration and involving simple surveying description and sampling procedures, was carried out in the Buttes area of the Navajo Indian Reservation in northeastern Arizona. The test was conducted on some of the volcanic rocks of a diatreme of Pliocene age north of the Castle Butte trading post. The topographic relief is moderate in the part of the diatreme tested, and the area tested could probably be negotiated by a man in the Apollo developmental spacesuit used in the August 1964 tests at Bend, Oregon. The weather during the test was poor, and the accuracies of some of the measurements could undoubtedly have been improved with better lighting conditions.

The following pieces of equipment were utilized in the tests:

1. Surveying staff with vertically mounted, optical range finder (20 cm base).
2. 35 mm film camera mounted on the surveying staff so that optic axis is perpendicular to staff and parallel to optic axes of range finder.

3. Open-sight alidade on a tripod mounted plane table.

4. Sample apron.

5. Prenumbered sample bags.

6. Geologist's pick.

7. 10X hand lens.

8. Two portable, 2-way, hand keyed radios.

9. Tape recorder.

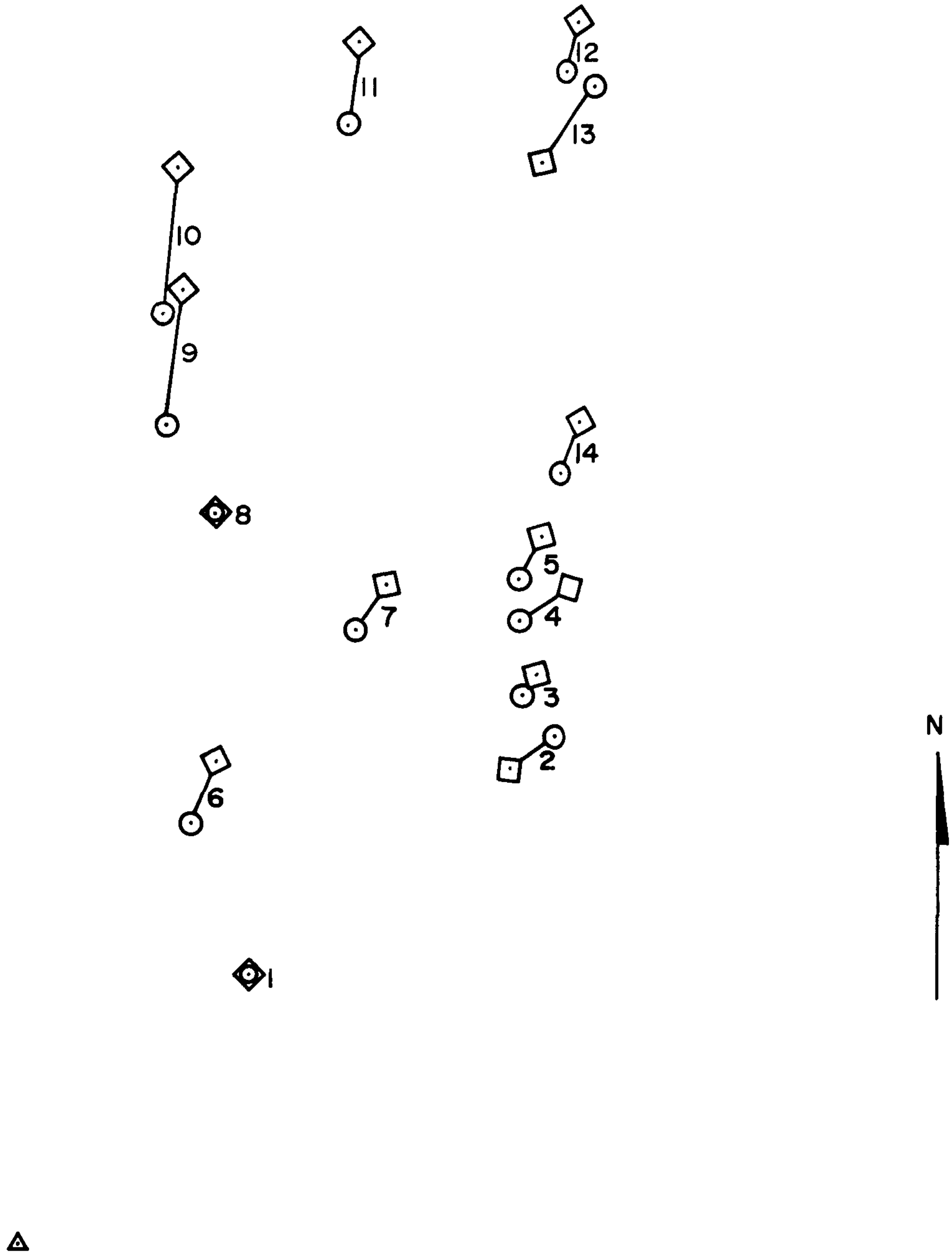
10. Measuring scale.

During the test, each traverse station was surveyed using the optical range finder and open-sight alidade. The open-sight alidade was used only on a plane table at the base station; however, the range finder was operated both from the surveying staff and from the base station. Little difference was noted between the two methods of range

base station the observer spent less time at a given station.

Each surveyed traverse station was flagged during the test and then resurveyed after the test using a telescopic alidade, plane table and stadia rod. A comparison of the test survey net with that obtained from the conventional methods is shown in figure 5.

During the test, the geological descriptions and surveying data were transmitted by radio to the base station and a plot of the geology was made immediately following the transmission. The map produced is shown in figure 6. A control geologic map was compiled after the test using the control survey net (figure 5) and any additional survey points that were deemed necessary to portray the geology of the test



Explanation

△ Plane table station.

○ Station located with open sight alidade and optical range finder.

◇ Station located with telescopic alidade and stadia rod.

--Control nets for geologic maps in figure 6 and 7. Stations first established with open sight alidade and 20 cm (7.8 in) base optical range finder, then resurveyed with telescopic alidade and stadia rod.

site at the scale employed. This control geologic map is shown in figure 7.

All of the equipment used in the test, in concept if not in design, potentially could be used on the lunar surface or in the LEM. The optical range finder could be used either by the surface astronaut or from the LEM. The imaging system employed during the test was a film camera, mounted next to the range finder on the surveying staff so that the range to points in the image can be determined. The photographs can be used later to refine the detail around a survey point. The open-sight alidade and plane table combination could be used from within the LEM, provided the surface astronaut stayed within view of the LEM windows. The principles of all these surveying instruments could be incorporated into an exploration periscope without any basic change in operating procedure.

The geological descriptions and surveying data transmitted to the base station were recorded on a small portable tape recorder, and were monitored by the plane table operator at the base station. At the end of each description, the plane table operator helped improve the transmitted map details by supplemental questions. Although feasible in concept for lunar work, the use of standard, hand keyed 2-way radios and a limited capability recorder caused considerable delay and inconvenience during the test. A more suitable radio and recording system should be available for future tests.

Samples along the traverses were obtained with a geologist's pick. They were collected in prenumbered sample bags and carried

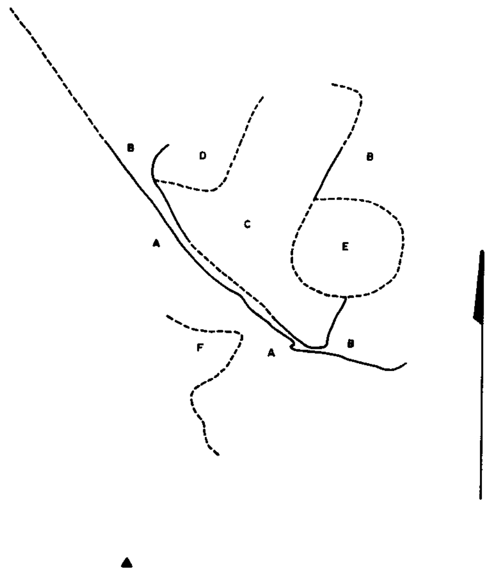


Figure 6.--Geologic test map for traverse mapping. Distribution of units compiled from data transmitted by two-way radio during test. Location of data points based on open-sight alidade-optical range finder survey net shown in figure 5.

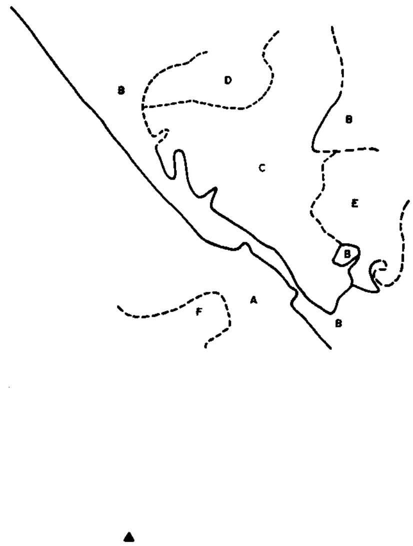
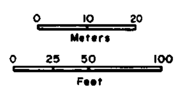


Figure 7.--Geologic control map for test map shown in figure 6. Location of data points based on telescopic alidade-stadia rod survey net shown in figure 1.

EXPLANATION

———	CONTACT OBSERVED WITHIN 0.5m(1.5feet)
- - - -	CONTACT, APPROXIMATELY LOCATED
△	PLANE TABLE STATION
A,F	ALLUVIAL UNITS
B,C,D,E	VOLCANIC UNITS



in a carpenter's nail apron. Fourteen samples weighing a total of about one kg and averaging approximately four cm in diameter were collected during the one hour and 50 minute test mission. Preliminary examination of these samples suggests that the sample size and number is adequate for most scientific purposes.

The film camera was employed to take black-and-white photographs of the geological features at each traverse station. In addition, a pair of horizontal, parallel axis, color stereo-photographs of the map area were taken on self-developing film. These photographs and analytical data from the samples will be used in future work to improve the quality of the test map.

Conclusions.--The field test of this particular type of traverse mapping, although limited in scope, allowed the following conclusions

1. The 20 cm base (7.5 in) base optical range finder is adequate for most geologic mapping purposes to a distance of about 60 m (200 ft).
2. The 20 cm base optical range finder is a useful aid to sketch mapping to distances of at least 120 m (400 ft).
3. The above maximum distances may be increased with better lighting conditions.
4. A 20 cm base optical range finder would be useful for detailed geologic mapping in an area where a control net was previously established on a maximum of about 85 m (280 ft) centers.

5. Relative bearings determined by open sight alidade are accurate enough for most geologic mapping purposes to distances of at least 120 m (400 ft).
6. The plotting of the geology of an area during a mission, even in rough form, aids in effectively directing a mapping operation.
7. Even if ranging on the surface astronaut's position is performed from the LEM, either manually or automatically, the surface astronaut should have a ranging instrument on the surveying staff so that points hidden from the base station can be surveyed.

Future operations.--The field tests indicate that the following additional variations of traverse geologic mapping should be investigated:

1. Substitute the use of a sun compass on the surveying staff for the open sight alidade in the determination of bearing.
2. Test the use of a sun compass in combination with a staff mounted range finder or portable telescopic alidade in an area covered by a survey net on centers commensurate with the ranging instrument employed.
3. If 2, above, proves feasible, develop methods applicable to lunar geologic mapping for the establishment of a suitable control net such as telescopic ranging, electronic ranging, and photogrammetric ranging.

4. Test the feasibility of fully automated surveying during traverse mapping and develop procedures for fully utilizing such a method.

Geologic Section Measuring

(G. A. Swann, P. T. Barosh and W. J. Rozema)

General Statement

The geologic expression "measuring a section" usually implies that the thickness of individual units of a sequence of stratified rocks are measured and the units described, sampled, and checked for local variations in directions parallel to the unit contacts. There are, additionally, some techniques by which the thickness of the section is measured and the rocks are described from a remote position on the basis of their surfacial characteristics. The individual operations involved in section measuring, that is, measuring, describing, and sampling, are basic to detailed geological exploration.

Section measuring techniques can be applied to any type of stratified rocks. On the Moon such techniques may be useful in studying and describing interlayered volcanic flows, ash or cinder deposits, impact ejecta blankets, and lunar "soil profiles," so that correlation of rock units can be made within and between landing sites. Lunar sections of this nature may be exposed in the walls of large impact craters and in areas of faulting and other tectonic activity.

During preliminary reconnaissance of an area to be geologically mapped, section measuring will often help to familiarize the worker with the rocks of the area. It may help to determine the scale and detail necessary for geologic mapping in the area, and, in particular, help in the selection of mappable units. The information gained from measuring a stratigraphic section may serve to correlate units within this section with those in another section situated anywhere from a few hundred feet to hundreds of miles away. This information also supplies a basis for determining the nature of the structure of deformed strata that includes units of a previously measured section. The characteristics of the rock units, including variations parallel and perpendicular to the unit contacts, aid the geologist in interpreting the origin and history of the units.

A stratigraphic section can be measured, described, and sampled with virtually any amount of detail and accuracy, depending upon the purpose of the work. For geologic reconnaissance, estimates or rough measurements of thicknesses, the division of the section into coarse units, brief descriptions, and a few samples may suffice for approximate correlations and certain genetic interpretations. However, a

may require much greater detail and accuracy, and the division of the section into very thin units.

Common methods used in section measuring on Earth include direct measurement of the units with Jacob's staff (an adjustable staff with an attached hand level), chain and hand level, or plane table and telescopic alidade. Combinations of these methods are commonly employed. Indirect measurements and estimates of rock types are commonly made by photogrammetric methods on aerial photographs. The method picked depends upon the attitude of the layers, topography, and desired accuracy and detail. Aids to description, such as a hand lens, a standard color chart, and a description guide, are commonly used.

Any of the above methods might be applicable to lunar exploration. In gently dipping strata exposed on moderately steep slopes, the Jacob's staff, the lunar surveying staff and hand level, or horizontal-axis stereo-photography would probably be most applicable for the measuring of a section. In moderately to steeply dipping strata on relatively flat terrane, the use of a surveyed traverse with the determination of unit contact positions and orientations might be required. As with most geologic field work, the complexity, amount of exposure, and local topography affect the methods used and amount of detail required; even the purpose of the study may be partially controlled by these factors.

Field Test Operations

Field tests on section measuring have been conducted near the Castle Butte Trading Post in the Buttes Area of the Navajo Indian Reservation. The tests involved several methods and types of equipment, which in concept, if not in design, could conceivably be used during lunar exploration. Geologic control for the evaluation of the tests was established by standard methods of known usefulness and precision. The tests were designed to provide data on the time, quality, and quantity of the operations involved in section measuring that may be required as parts of possible lunar scientific missions tests. The following general operations were tested:

1. Remote description as compared with on-site description.
2. Section description and interpretation using photographic techniques.

3. Description under some possible mission constraints as compared with standard methods.

4. Selective sampling as compared with programmed sampling.

5. Remote or indirect measuring techniques involving photographic measuring and visual thickness estimation as compared with on-site measuring techniques.

The data gained during the measurement of a control section for the evaluation of the test data also provided necessary data on rocks exposed in this and other potential sites for mission tests.

The field tests were conducted on a well exposed sequence of flat-lying sedimentary units comprising parts of the Triassic Wingate and Chinle Formations, and the Pliocene Bidahochi Formation. The exposures are present on the sides of a mesa, one mile east of French Butte.

of the methods could be compared and evaluated in terms of time spent versus information and accuracy obtained.

The test, or lunar prototype, methods were carried out by geologists who were unfamiliar with the local area, in order to eliminate as much bias as possible from descriptions and interpretations. The control geology was obtained by geologists with roughly the same training and experience as that of the geologists performing the lunar prototype operations. The data obtained during the test are given in Chart I(in pocket) and in Appendix D. A summary of the methods and equipment used during the control geology and test operations appears in table 3.

Table 3.--Methods and Equipment Used During Field Tests of Stratigraphic Section Measuring

1. Geologic control (Section A in Chart I and Appendix D)

   a. Methods and equipment

      1) Three men on outcrop

         a) One describing units, using written notes

         b) One measuring thicknesses with Jacob's staff and taking samples

         c) One timing individual operations of other two

      2) Stratigraphic section surveyed with plane table, telescopic alidade, and stadia rod to check thicknesses obtained by Jacob's staff measurements

      3) Samples selectively taken to be representative of units

2. Test operations for lunar missions (Sections A1, A2, and A3 in Chart I and Appendix D)

   a. Test Operation One: remote description (Upper portion of Section A1)

      1) Unit contacts mapped on black-and-white, horizontal-axis, stereophotographic pairs taken before the test with self-developing film. A 2X pocket stereoscope used as aid in mapping.

      2) Stratigraphic section surveyed with plane table, telescopic alidade, and stadia rod to check thicknesses obtained by Jacob's staff measurements.

3) Attempt made to estimate lithologies based on previous geological experience in other areas.

4) Thicknesses of units measured from horizontal-axis color photographs after return from field. Units appear as color bands on side of mesa. True thickness of one unit in middle of section was known. From the known unit, a ratio was established by which the approximate true thicknesses of other units could be measured from their apparent thicknesses on the photographs.

b. Test Operation Two: remote description (lower portion of Section A1).

recorder was used instead of written notes.

c. Test Operation Three: remote description (upper portion of Section A2).

1) Unit contacts mapped on over-lay on black-and-white, horizontal-axis photograph taken with self-developing film before test.

2) Written notes referenced to units delineated on photograph.

3) Description guide developed and employed during test.

4) Standard color chart employed.

5) No attempt made to estimate lithologies.

Table 3.--Continued. Methods and Equipment Used During Field Tests of Stratigraphic Section Measuring

d. Test Operation Four: remote description (middle portion of Section A2).

   1) Same methods as in Test Operation Three, except that 6 x 30 binocular field glasses used to aid description.

e. Test Operation Five: remote description (lower part of Section A2).

   1) Same methods as in Test Operation Three, except that description was made from colored, horizontal-axis, stereophotographic pairs after return from the field area. A 2X pocket stereoscope was used to aid in description.

f. Test Operation Six: on-site description, sampling and measuring by one man (lower portion of Section A3).

   1) Unrestricted description aided by 10X hand lens and geologist's pick, and transmitted by hand-keyed, 2-way radio.

   2) Transmitted description monitored and recorded on tape by man at base station.

   3) Section measured with surveying staff having an attached Abney hand level.

   4) Selective sampling of each unit aided by geologist's pick and prenumbered sample bags.

   5) Programmed sampling at one staff length (137 cm) intervals.

Table 3--continued. Methods and Equipment Used During Field Tests of Stratigraphic Section Measuring

g. Test Operation Seven: on-site description, sampling, and measuring by one man (middle portion of Section A3).

   1) Same methods as in Test Operation Six except for use of a brief description guide and a standard color chart.

h. Test Operation Eight: on-site description, sampling and measuring by two men (upper portion of Section A3).

   1) Unrestricted description by one man aided by the second man and by a brief description guide on surveying staff, a standard color chart, a 10X hand lens, and a geologist's pick.

   2) Measuring and sampling by second man using a surveying

   pick, and prenumbered sample bags.

   3) Programmed sampling at one staff length (137 cm) interval.

   4) Descriptions, measuring data and sample numbers transmitted by hand-keyed radio to tape recorder at base station.

Comparisons of Standard and Test Operations

Measurement.--The thicknesses of the control section measured with a Jacob's staff match very closely those measured with a telescopic alidade and a stadia rod. The total error was 3.9%. A comparison of the two methods is given below:

Units	Thickness by Jacob's staff	Thickness by alidade and stadia rod
14-22	84.5'	84.5'
23-32	92.0'	100.2'
33-44	40.5'	39.3'
45-55	58.75'	56.5'
55-66	93.0'	103.3'
	368.75'	383.8'

The thicknesses of that part of the section measured with the surveying staff on the outcrop (Section A3 on Chart I) are virtually the same as those measured with conventional equipment (Units 4 through 11 in Section A on Chart I). This indicates that the surveying staff is a suitable substitute for the Jacob's staff and Abney level. The time spent in measuring the thickness of 13 units with a Jacob's staff ranged from 0.01 to 1.03 minutes with a mean of 0.52 minutes. The thickness of these units only varies from 1 foot to 10 feet, which is an insufficient range to establish a correlation between measuring time and thickness.

That part of the section measured from a photograph using a reference unit of known thickness is sufficiently accurate for fairly detailed reconnaissance work (Section A in Chart I). The thickness of the upper half of the section as measured by this method is slightly less than the actual value, and the lower half is slightly thicker. This is due to the slope of the line of the section which results in a change in scale on the horizontal-axis photographs: the lower half of the section becomes progressively larger in scale down-slope from the reference unit (toward the observer), and the upper half becomes progressively smaller in scale up-slope from the reference unit (away from the observer). Two reference units, one near the top and one near the base of the section, would suffice to correct this error in exposures on a uniform slope.

be made after the return of photographs to Earth, provided reference thicknesses are obtained. If the photographic characteristics of the rock units are sufficiently distinct and described units can be identified, this method of measurement can be substituted for on-site measurement with a considerable saving of exploration time.

The thickness of the section based entirely upon visual estimation (Section A2 in Chart I) is about one-half the true thickness. As the relative thicknesses of units are similar, this degree of accuracy might be acceptable for rough reconnaissance work.

Sampling.--Studies on the adequacy of samples are somewhat subjective in nature and have not been completed to data. The most efficient sampling method to get representative samples of the rocks present is dependent on the nature of the rocks and the scale of significant variations in them. A preplanned sampling program without regard to the nature of the rocks is likely to give either insufficient samples to represent the rocks (as was the case using a one staff length as the sampling interval in Section A3), or too many nearly identical samples (as would be the case if a sampling interval were chosen that was relatively small in comparison to the thicknesses of the units). Sampling should be planned according to the nature of the rocks and the purposes of the study. Decisions as to the sampling procedure may have to be made on the spot, although many of the various rock characteristics to be encountered can be anticipated and a general sampling philosophy established.

The times required to obtain and package 11 samples taken during the measurement of the control section (Section A on Chart I) ranged between 3 and 23 minutes, with a mean of 7.5 minutes. The rocks are of relatively good and uniform exposure but are composed of soft material in which it is commonly difficult to obtain a coherent sample. The sampling time for 10 of the 11 samples ranged between 3 and 11 minutes, which is less than the range usually encountered in areas of varied rock types, exposure, and topography. It is clear that the assignment of sampling times for lunar exploration can at best be made only very roughly and in most instances cannot be predicted until the general nature of the rocks and the exact purpose for which the samples are to be taken are known.

Description.--Evaluation of the adequacy of descriptions obtained by different methods must be somewhat subjective, but some generalizations can be made concerning the results of the field test. The use of recorded voice descriptions rather than written notes did not appreciably affect the time of the operations (see times per unit in Section A1 on Chart I), but the descriptions were somewhat more detailed where they consisted of recorded voice than where they consisted of written notes (see Section A1 in Appendix D). The geologists involved in the test were thoroughly familiar with the use of notebook and pencil, but were somewhat unfamiliar with giving systematic and concise verbal descriptions of their observations. This suggests that, with training, spoken descriptions could be performed more rapidly than written descriptions.

descriptions (table 4), and were found especially useful when using a tape recorder to record the observations. Much of the necessity for description guides arises from not being able to check back, as can be done with written notes, to see that all pertinent points have been covered. Another disadvantage of tape recording is that it is difficult to remember such things as sample and station numbers. It was found useful during the tests to have one man monitor the verbal numbering and check the verbal description against a description guide. Such monitoring could be performed by either the man in the LEM or by Earth-based scientists. Questions regarding omitted items or for clarification were best withheld until the observer indicated his

Table 4.--Test description guides for on-site and remote descriptions of stratigraphic sections.

Description guide employed in the on-site description of Section A, Appendix D.

Rock type(s),(modifier): if more than rock type, describe primary type first, then secondary).

Color(s): fresh, weathered (if color bands, list also width, length, irregularity and percent of unit or number).

Matrix: grain size, (grain size range), sorting, roundness, acid reaction, composition, (cement), (luster), (orientation of particles).

Lateral extent of unit minimum or maximum, (veins), (joints).

Bedding, (sedimentary structures).

Weathering characteristics.

Minor rock types.

Contacts: conformable or not, upper contact, (variation in thickness of unit), (lateral variations).

The items in parenthesis are noted if present or visible. The items covered in the description guide are primarily for sandstones, siltstones and claystones. The number of features that can be practically described decrease with decreasing grain size. Roundness and composition are generally left out of the descriptions of siltstones and mudstones. Grain size, sorting, roundness and composition are generally left out of the description of claystones and some mudstones.

Description guides employed in the remote description of section A2, Appendix D.

Unit number

General characteristics

Internal layering characteristics

Color

Thickness

Table 4.--Continued. Test description guides for on-site and remote descriptions of stratigraphic sections.

Internal layering characteristics--continued

Reflectivity (relative to units in area with the lowest and highest reflectivities)

Texture of exposed surface

Relief on exposed surface

Vegetation

Fractures

Contacts

Internal

With underlying unit

Genetic possibilities

readiness for them. This prevented interrupting the observer's train of thought while he was working.

One of the remote description tests was an attempt to estimate the lithologies of the units described (Section A1 on Chart I), and a comparison of the estimated lithologies with the control section (Section A) shows that most of these estimates were reasonable but not precise. These estimates consist of "educated guesses" based upon the geologist's familiarity with the weathering characteristics of various rock types under various terrestrial conditions. This type of estimation on the Moon undoubtedly will become useful as additional knowledge is gained of the lunar surface properties, particularly after one or more manned landings.

A similar amount of detail and accuracy was derived from describing the section from color photographs as was obtained from the remote field description with the unaided eye (Parts I and III, Section A2 on Chart I and in Appendix D). Unless the information is necessary to a particular lunar mission, it would be better, if possible, to take photographs, annotate them where appropriate, and complete the descriptions from the photographs after their return or transmission to Earth.

Probably the best test of the adequacy of remote descriptions is the ability to correlate sections described from a remote position with one described on the outcrop. The tests indicate that fairly accurate, but not highly detailed, correlations can be made between the descriptions from remote localities with those made on the outcrop (Chart I). The correlations in this section are based mainly on the color sequence and the frequency of internal variations in rock units; in other sections the same procedure might be used to correlate units on the basis of outcrop form, such as changes in slopes and the detailed erosion characteristics.

The description of the colors of the weathered units observed remotely and those observed on the outcrop are highly variable in detail, although adequate for the gross correlation of sections if the sequences of colors can be compared (see correlation columns on Chart I). The variability between the standard color chart colors given for the same units in Sections A and A2 is a reflection of the distance from the outcrop, the lighting conditions and the individual's experience in using the color chart. No standard color chart was used for Section A1.

linear features on the surface of the slope. These features formed as a result of weathering, erosion, and rock characteristics. The forms are graphically illustrated in Test Section A2, Chart I, and may provide clues for correlation with other stratigraphic sections that have been measured from remote stations.

Discussion of Times to Perform Operations

Because the section measuring from a remote locality consisted only of marking photographs and describing the units, times of the individual operations were not recorded. Measurement on the outcrop consisted of sampling, measuring, and describing, and times required to perform the sampling-measuring and the describing operations were recorded. Differences, in some cases very pronounced, exist between the time required to perform a given operation in one unit and the time required to perform the same operation in another unit. These differences can be ascribed to a number of factors: variations in complexity, topography, exposure, thickness, and rock type, besides human factors. The variations in times indicate that no more than an average can be assigned to the time necessary to perform an individual operation, and that the actual time required to perform this operation may deviate from the average so greatly that the average has no significant meaning to the individual case (see table 5).

The cumulative time curves on Chart I, although irregular, indicate that operation time varies approximately linearly with thickness, provided no major changes in the general character of the rocks are encountered and no changes in procedure are made. This indicates that under conditions of known geologic and topographic complexity, the rate at which section measuring will proceed can be approximately predicted even though the time for a specific part of the operation sequence cannot be predicted.

The irregularities in the cumulative description time curve as plotted against thickness (Section A on Chart I) show two patterns: a marked general decrease in slope, approximately two-thirds of the way above the base, where the section is divided into thinner units than below, and a number of steeper portions opposite the thicker units. This indicates that the description time is more a function

Table 5.--Time and operation data for Geol 1 Section Measuring. Data obtained during measurement ction A (Appendix D)

Item	Mean Time in minutes	Stand Deviat	Coefficient of Variation	Number of Measurements	Range Min. (in minutes)	Range Max. (in minutes)
Description time per foot of section	7.74	10.3	133%	65	0.32	54.00
Description time per stratigraphic unit	20.5	11.4	55%	65	6	53
Description time per lithology	16.0	3.2	20%	41	5	60
Total description, measuring and sampling time per stratigraphic unit for two men	32.1	18.5	58%	48	11	92

Item	Mean Time in minutes	Mear Desc	cent of ion Time	Number of Measurements	Range Min. (in minutes)	Range Max. (in minutes)
Hand lens use time per stratigraphic unit	1.04		%	11	0.17	2.75
Rock color chart use time per stratigraphic unit	2.13		%	12	0.67	4.00
Jacob's staff use time per stratigraphic unit	0.52		%	13	0.01	1.03
Sampling time per stratigraphic unit	12			11	3	27
Approximate sampling time per sample	7.5			17	3	23

of units than thickness and a straighter curve would be produced when the description times are plotted against units. This is expressed statistically in table 5. The description time per foot of section was found to have a coefficient of variation of 133%, whereas the description time per unit has a coefficient of variation of 55%.

The majority of units represent essentially single rock types; however, a number of units contain more than one. All other things being equal, more time is spent describing two rock types than one, and more time is consumed on units with two rock types than on units with one. Thus, description time should show even a closer relationship to rock types than to units. This is shown in table 5.

In describing a unit in Section A, a number of samples were examined with the use of a hand lens (a small, 10X - 14X magnifying lens), and the colors were described using the standard Geological Society of America Rock-Color Chart (1963). Times for these two operations were collected for a limited, but representative, number of units. The evaluation of this data is given in table 5.

The total time per unit for a two-man operation, including the description, sampling, measuring, and the laying out of the section, ranged from 11 to 92 minutes, with a mean of 32.1 minutes. In addition, 60 minutes were spent in detailed planning where the section was to be measured, and this time should be distributed over the units. This would add 0.90 minutes to the mean time per unit.

No appreciable change in slope occurs in the cumulative time curve of the remote description that was made entirely with the unaided eye, using both written notes and verbal recording (Section A1 on Chart I). This suggests that for the case of that individual observer and his degree of familiarity with verbal description, no appreciable time is saved by using recorded voice description.

The time required to describe a unit appears to increase if binoculars are used, as opposed to descriptions made with the unaided eye (parts II and III of Section A2 of Chart I). This is because more detail can be seen with the binoculars and thus there is more to describe. No appreciable change can be detected concerning the time required to describe a section with the unaided eye from a remote locality in the field as opposed to the time required to describe the section from color stereographs in the office (parts I and III of Section A2).

Supplementary Information [illegible]

A short exercise was performed to test the feasibility of mapping and describing geologic features in addition to stratigraphic units from a remote position by compiling a non-planimetric map on horizontal-axis photographs. To accomplish this, unit contacts were drawn as they appeared on the photographs, giving an oblique map view that has a pronounced decrease in scale from foreground to background. This method appears very useful for areas of moderate to great relief. With proper control of the photography, quantitative spatial relationships can be obtained by photogrammetric methods and the information plotted on a planimetric base. More detailed tests on photographic mapping will be performed in the future.

Conclusions

The following conclusions and recommendations are made on the basis of the field tests on section measuring:

1. The rate at which a section can be measured under conditions of known geologic and topographic complexity can be approximately predicted.
2. The rate at which a section can be measured is more dependent on the number and character of the units than on the unit's thickness, therefore the size of the units chosen is very significant in determining the rate. A section divided into 100 to 200 m thick units could be measured considerably faster than if the section needed to be divided into 1 to 5 m thick units.
3. The rate at which samples are collected, even in fairly uniform rock types, varies greatly, and sampling times cannot be predicted unless a great number of samples from each rock type are involved.
4. Recorded voice descriptions should be used rather than written descriptions. It will probably be difficult to manipulate writing material on the lunar surface, and more detail can be recorded than can be written in a given amount of time. The observers should be thoroughly trained in dictation. Concise and objective description guides should be developed for training purposes and to assure that necessary information is recorded. Monitoring

of descriptions by the man in the spacecraft and by scientists on Earth will be helpful, provided questions regarding the omissions and clarifications are made on request, are kept to a minimum, and are directly applicable to the problem at hand.

5. Descriptive information gathered on the Moon should be supplementary to that which can be obtained from returned photographs and samples. It should duplicate photographic and sample data only insofar as the information is necessary to the conduct of the mission.

6. The surveying staff is an adequate substitute for the Jacob's staff in section measuring.

7. Photographs available during a mission are very useful

data. Thus, self-developing film would be useful to the astronauts. Good photographs would allow some measurement and description to be made upon return to Earth. These photographs could be annotated in critical areas by the astronauts while on the Moon.

8. Stereophotographic pairs are helpful in determining the weathering and erosional characteristics of rock units.

9. Because variations in color were very important to remote description of the section measured, color film was much more useful than black and white film.

10. Detailed measurement of thick stratified sections will be probably unlikely on early Apollo missions due to the time required to perform these operations. A very limited amount of section measuring might be done in selected areas that are critical to the solution of an important problem. Remote measurement could be performed on longer missions involving a roving vehicle or LEM/Shelter, if the measurement is a necessary aid to exploration during that mission.

Petrological Analysis for Lunar Field Geological Operations

General Statement

(J. T. O'Connor, H. H. Schmitt, G. A. Swann)

The study of the natural history of rocks by all available methods is the field of investigation denoted by the general term "petrology" (Howell, 1957, p. 218). Petrological analysis on the lunar surface during LEM/Shelter or mobile laboratory missions potentially could include a broad range of laboratory techniques, including microscopic petrography, X-ray diffractometry, X-ray spectrometry, mass spectrometry, gamma ray spectrometry (with or without a neutron source), optical spectrometry, and alpha particle spectrometry.

Some techniques of petrological analysis will be of prime importance [illegible] of LEM/Shelter and mobile laboratory missions on the moon. The [illegible] of missions of this type will create special problems in the selection of samples to be returned to Earth, exploration planning during the mission, drilling site selection, and geophysical and geochemical instrument station selection that do not arise during the short exploration time of the early Apollo missions. The effective and efficient solution to the problems will contribute greatly to the overall success of each lunar mission.

The project's investigation of the petrological analysis for lunar exploration is directed toward developing the techniques that will solve the following mission problems:

1. The efficient selection (for return to Earth) of the most scientifically valuable samples from the many to be collected during field operations.
2. The collection of useful comparative data on samples to be discarded, in particular, those data that indicate the areal distribution of mineralogical, chemical, and structural variations in lunar materials.
3. The integration of petrological data into mission operations so that sampling, description and mapping programs can be refined during the mission.
4. The analysis of the effect of the composition, texture and physical properties of local materials on geophysical and geochemical experiments so that refinements of such experiments are possible during the mission.
5. The determination of the engineering properties of lunar materials so that potential hazards to the mission can be anticipated, optimum mobility systems developed, and sites for future missions and lunar bases can be selected.
6. The analysis of petrologic data received on an Earth-base during a mission and its use in helping to direct the conduct of the mission.
7. The determination of specific objectives for sampling and petrological analysis during given missions.

In developing the techniques of petrological analysis for lunar exploration, the following related problems are being studied:

1. What instruments are available, how should they be modified, and what new instruments should be developed to obtain and interpret petrological data during mission operations.
2. How the nature of lunar surface materials will affect the choice of the instruments to be incorporated in a given mission. In particular, how the conduct of petrological analysis of lunar material will be affected by the possible variation in their origin, chemical composition, mineralogy, crystallinity, rock type, particle size and induration, depth of burial, engineering properties, and mode of sampling.

In conjunction with the investigation of petrological analysis for lunar exploration, petrological control of various test sites is being obtained. This control will aid in the evaluation of the usefulness of

obtaining useful samples, and field and petrological data.

Results of Preliminary Investigations

(J. T. O'Connor)

The basic tools necessary for petrological analysis are those presently utilized by petrologists in studies of terrestrial materials. These tools are the petrographic microscope, X-ray diffraction instruments, classical chemical analysis and spectro-chemical analysis equipment, radiation analysis equipment, and strength of materials devices. These tools have individual advantages and disadvantages and are discussed separately below. Additional information on some of the tools of petrological analysis is given by Weber and others (1964).

Petrographic microscopy.--The optical properties of terrestrial minerals as seen in thin sections of rocks are, in general, well known and have been correlated with the chemical composition and crystalline structure of the minerals (Wahlstrom, 1960; Tröger, 1956; Winchell and Winchell, 1951; Deer and others, 1962-1963). The examination of thin sections with a petrographic microscope permits direct observation of textural features of a rock including fracturing, porosity, rock fabric, and the effect of external agents on the rock (i.e., chemical alteration and the effects of heat, pressure and radiation). Thin section analysis would be an extremely useful method of sample selection for determining typical and atypical samples to be carried back to Earth for further analysis. In addition, many rock thin sections could be returned to Earth without the parent samples, giving a better cross section of lunar materials than that available from fewer, larger and heavier hand samples. Each thin section would also be amenable to electron microprobe analysis. Further information would be possible from thin sections not returned if they were photographed and briefly described before being discarded.

The possible weight and efficiency of the petrographic microscope and supporting equipment, particularly the devices necessary for preparation of thin sections, are currently being investigated. The microscope itself should not present great weight difficulties. Using the optical train of a modern research petrographic microscope and a light weight frame, the microscope would weigh about five pounds.

Preparation of rock thin sections requires facilities for cutting and grinding rock specimens. Estimates from optical firms with experience in this field suggest that self-contained packages of about 10 pounds weight each can be developed for each of these operations. The cutting and grinding equipment would probably consist of high speed diamond impregnated wheels designed specifically for such operations. The mechanisms would be at least semi-automatic, requiring no more attention than loading and removing samples.

A limiting factor in the usefulness of petrographic analysis would be a preponderance of isotropic material on the lunar surface--either of volcanic origin or as a result of impact and radiation effects on previously crystalline material.

X-ray diffraction.--X-ray diffraction is a most versatile tool

may determine the bulk mineralogical composition of rock samples, variations in crystal lattice parameters that reflect chemical variations in the minerals and variations in the structural state of crystalline material, the crystallinity of materials, and particle size and orientation. In addition, the technique is capable of dealing with particle sizes well below those necessary for optical methods, thus allowing mineralogical determinations in the realm of devitrification and chemical alteration phenomena. X-ray diffraction is also useful for opaque materials or materials with refractive indices too high for normal petrographic determinations. The major components of X-ray diffraction equipment also are compatible with equipment for the spectrochemical technique of X-ray fluorescence spectroscopy.

The sampling problems are minimal for X-ray diffraction; all that is needed is a few tenths of a gram of powdered material. The exposure of serial samples to X-radiation and recording of diffraction patterns has been automated in many existing facilities.

Time considerations may be a detriment to the use of X-ray diffraction during lunar exploration. The reduction of power due to the reduction of equipment size increases scanning time if everything else is held constant. Two methods of overcoming this problem are apparent. One is increased sensitivity of detection with the conventional line-by-line scanning. The other is total scanning of all lines at once. Total scanning has been productive in experiments at several institutions working on the general properties of X-ray diffraction. The method would cut scanning times by at least one order of magnitude.

The primary difficulty with the X-ray diffraction technique as with the microscopic petrography is the nature of the lunar surface material. Destruction of long-range order in crystalline structures will destroy the diffracting properties of the structures, rendering them isotropic to X-rays. If the Moon's surface is covered with material so severely shocked or irradiated that its crystallinity has been destroyed, the usefulness of X-ray diffraction would be limited to the examination of subsurface material. Experimental work and the results of the early Apollo missions are necessary to elucidate this problem.

Analytical chemistry.--Instrumental chemical methods offer many possibilities for use in lunar missions. Much of this field has been covered in the report, Survey of lunar measurements, experiments, and geologic studies by Texas Instruments Inc., Contract No. NAS 9-2115, final report. Two of the instruments commonly used in solving geological problems are discussed here.

X-ray fluorescence is one method of obtaining chemical compositions (for all but the lightest elements) of rocks and minerals. Some of its biggest advantages are the compatibility with X-ray diffraction and its adaptability to solid samples. Difficulties in power generation and size have been reduced by research at the Jet Propulsion Laboratory for the Surveyor program. Necessary sample sizes have been greatly reduced by work carried out in the U. S. Geological Survey laboratories. Again, a reduction in operating time might be obtained by scanning the entire spectrum in one operation.

In the case of preponderance of glassy phases on the lunar surface the electron microprobe may prove to be the only instrument which will

special case of the X-ray fluorescence apparatus, it is operable even in the absence of long range crystalline order as it analyzes the characteristic X-ray emissions of the elements. By scanning a specimen for X-rays that are characteristic of a given element, images showing the distribution of the element can be obtained. Thus the chemical texture of amorphous material can be determined and used for the same purposes as the mineral texture of crystalline aggregate.

Geological sampling.--The most restrictive problem in petrological analysis, as in most geological analysis, is sampling. The information obtained from the most meticulous analysis can be no more representative of the rock than are the samples collected. The methodology of sampling will therefore be carefully examined in the present study. The first criterion in selecting sampling programs must be the validity of the programs in relation to detail sought in the analysis. Two types of sampling programs, geometric and subjective, and combinations of these programs are possible.

The first type is geometric (or random) sampling. A geometric sampling program is random if no weight is given to features of the sampled area. This is the sense in which geometric sampling is taken in this report. This type of sampling program presupposes no geologic training of the sampler and is set up independently of the geology of area to be sampled, except for considerations of the scale of its geological heterogeneity. Samples are collected at nodes of a predetermined grid, along radii extending from a starting point, or in some other geometric configuration; or are selected at distances and azimuths determined by random selection.

Geometric sampling has its greatest value where variations in the properties of samples are below levels distinguishable by the field observer. It is also a very useful type of sampling program where trends or variation patterns may be present that are not readily apparent to the observer. This type of sampling program would thus be most valuable in a petrologically monotonous terrane. In a geologic terrane in which readily observable variation in rock types is the rule, an inflexible geometric sampling program will not sample each rock type with equal efficiency. These programs give unbiased information concerning the properties of areas, but the lack of bias immediately precludes an equiponderance of information on rock types of equal interest, but differing areal extents.

The efficient use of a geometric sampling program to supply petrological information on various rock types requires, first that the rock types be recognized, then that units be delineated, and finally that a sampling program be set up for each unit. This predicates that most of the desired information be collected before the sampling program is set up, defeating the very purpose of the sampling program itself.

Geometric sampling is usually employed as a mathematical aid in statistical analysis of data concerning a specific area; for instance in the search for hidden ore bodies. Because on the Moon, we shall be immediately concerned with all types of rocks existing within our range of operation and the extent of variation in their properties,

be used only in the case where preliminary observations show no appreciable changes in the material to be studied.

Scientific subjective sampling is an extension of geometric sampling (objective sampling in the statistical sense). In a subjective sampling program, the sampler is using his training and observational powers to continually compare the rocks being observed. He is thus able to judge what are the most important samples to collect for the purposes of the mission, to extend his observations outside the area of immediate occupancy, and to evaluate variations in his observations. This type of program will give a greater amount of information than the more restrictive geometric type, particularly when sampling time is limited. The fact that samples are taken subjectively, and not at predetermined points in a geometrical scheme, does not detract from their petrological significance. These samples should be described in relation to their environment, but may still be used to analyze (by statistical methods if desired) petrological variations.

A subjective sampling program is limited, of course, by the powers of observation of the sampler. It cannot be as completely time-scheduled as can a geometric program, owing to a necessary flexibility in the face of unpredictable geological conditions.

Within the framework of any type of sampling program, the question of what constitutes a petrologically significant sample must be answered. In distinct geological rock types this question is most easily answered by an on-the-spot decision. In extremely heterogeneous rock types (such as multilithic breccias or debris from craters), the size and number of the constituent particles will determine the size of a significant sample. In this type of material some form of channel sampling (with the accurate location of individual parts of the sample) will be necessary to completely account for the petrologic variation within the rock type. In very monotonous material, possibly any small piece will be a representative sample.

Some of the investigations and tests of the project are relating sampling programs and types of samples to particular geologic features:

1. The usefulness and statistical validity of various geometric sampling programs in monotonous terranes are being investigated.

2. Preplanned sampling traverses are being combined with subjective sampling methods on known geologic features.

3. Minimum sampling densities are being tested in areas of known geologic detail; the only restriction being placed on movement is the establishment of external boundaries. This type of sampling might be used to provide back-up information for an astronaut with limited field experience working on a particular geologic feature. It would be supplementary to a subjective sampling program carried on simultaneously.

4. The petrologic significance of different types of samples is being tested empirically and theoretically in relation to the heterogeneity of the rock sampled.

during LEM/Shelter and mobile laboratory missions, and the effect these techniques will have on setting up sampling programs are being evaluated.

Lunar Exploration Instrumentation

The Lunar Field Geological Methods project is conducting feasibility studies on several types of field instrumentation that may be useful during lunar surface explorations. With the assistance of R. M. Batson, R. R. Blecka, E. E. Butler, D. W. Dodgen, and E. L. Phillippi, the concepts of the instrumentation are being developed and working prototypes constructed for use and testing during mission development studies. Progress reports on the status of the instrumentation studies are given below.

Surveying Staff

(H. H. Schmitt)

The basis of the lunar surveying staff concept is the necessity of obtaining a scientific record of an astronaut's traverse, and of obtaining the spatial relations of data points in this record. The initial effort has been to develop and test a manually operated staff. By verbal transmission of data on orientation and position, this staff can provide sufficient information to establish the position and orientation of the astronaut.

The basic pieces of equipment for a manually operated staff include:

1. Sun compass with a rear sight
2. Single-axis pendulum clinometer
3. Two orthogonal line bubble levels mounted below and parallel to sun compass dial (for lunar work, this arrangement would probably need to be replaced by a hemisphere-ball, multi-axis clinometer; a two-axis, pendulum clinometer; or a gyroscopic clinometer).

4. Film camera with its optic axis perpendicular to the staff and parallel to the sight on the sun compass.
5. Vertically mounted optical range finder, or a telescope with stadia-hairs.
6. A surface scraper and a scoop on the end of the staff aid in the removal and sampling of loose material.

The limited amount of time available for lunar surface operations makes it desirable that geological surveying tasks be performed automatically whenever possible. In order to accomplish this, the following instrument systems are included in a concept for an automated surveying staff:

1. Television system.
2. Stereometric film camera or stereometric electro-

3. Orientation system.
4. Physical properties measurement modules.
5. Tracking system.

The hand oriented instruments required to obtain the prime image data of the fine structure of the lunar surface are best utilized near eye level. The incorporation of these instruments into the head of a surveying staff, whose position and orientation at a given time are accurately and automatically determined, permits the astronaut to direct talents and energy toward his field investigations, knowing that certain parts of the data are collected automatically.

The accurate and automatic determination of the position and orientation of the surveying staff locates features described or sampled by the astronaut. The positional and orientational data also allows the incorporation of physical properties measurement modules into the staff when required for special traverses or materials. The use of such modules would permit the accurate, spatial analysis of magnetism, radiation, and soil mechanics data relating to near surface materials.

The development of instruments to be included in the automated surveying staff and its supporting systems should emphasize the modular building block approach for both data acquisition systems and power sources. This concept provides for rapid and simple replacement of one instrument by another, a minimum of trouble shooting and repair equipment, and ease of instrument transport. Modular systems and sub-systems also give increased adaptability to changes in system requirements or sub-system quality.

The use of a surveying staff should be integrated with that of a walker for traverses over surfaces with low to moderate relief. The walker's major function, other than physical support, would be to carry samples and sample containers. It can serve, in addition, as a carrier for the staff, extra power modules, and instrument modules. In some cases, the walker can serve as a stable platform for geophysical modules and as a base station for electromagnetic experiments. The walker also would provide a support for the staff during special surveying and photographic operations, and operations that require two hands, such as sampling. By the use of attached, spring wound lines of given lengths, the walker would provide a base station for photogrammetric traverses requiring accurately measured base lines.

Exploration Periscope

(G. A. Swann)

A periscope on a surface spacecraft helps fulfill several scientific and safety requirements of lunar exploration. In particular, it allows the man in the spacecraft to be in direct visual contact with the man on the surface whenever necessary. The periscope will assure first-hand observation and imagery of the lunar panorama, with accompanying geologic and geomorphic descriptions and interpretations, in the event the astronauts do not leave the spacecraft. Direct visual [illegible] the surface will enable the man in the spacecraft to begin [illegible] left off, with a minimum of familiarization reconnaissance. The view through the periscope will utilize man's eye, and thus will not have undergone the image degradation that is inherent in optical and electronic imaging systems. A periscope will be more rugged than, and therefore an effective back-up device for, electronic imaging systems.

To effectively accomplish the above goals, a LEM periscope should have a tilting head designed to attain continuous tilt angles between -15° and +45°, and should be capable of being raised four to six feet above the top of the ascent stage (these values are subject to revision, depending upon the ultimate position of the periscope relative to the

LEM X axis, and the final configuration of the LEM and of outside installations such as antennas). It also should be designed to be rotated 360° about its vertical axis to give a complete panoramic view. Variable power is desirable, with powers on the order of 2X to 8X magnifications having 30° to 7½° fields of view, respectively. These specifications also will suit the special purposes outlined below.

A periscope of the above configuration will permit both panoramic and selected imagery of the lunar surface that can be either transmitted electronically or returned on film or tape for geomorphic and geologic description and interpretation on Earth. It is expected that a good film camera would yield close-up resolution, exceeding any electronic imaging device on Ranger, Surveyor, or Orbiter, or any practical film camera on Manned Orbiter. A camera equipped with a self-developing film pack would enable the astronauts to annotate the photographs from direct visual observations concerning features that are especially pertinent to a particular problem or that are not adequately portrayed on the photographs. Detailed descriptions and interpretations of the features in the photographs would then be made upon return to Earth in the light of the annotations and the features visible on the photographs. Annotations could also be made by the man in the LEM with respect to the descriptions made by the man exploring the lunar surface. This would be especially useful for placing described features in their relative positions during post mission photogrammetric compilation of imagery obtained by other methods.

Ranges to surface features up to 1000 feet away could be obtained through the periscope by an optical range finder with a horizontal base of about 2.5 feet. The periscope would also have to be equipped with a reticle for obtaining vertical angle; if properly designed and calibrated, this reticle would permit use of the periscope as a telescopic alidade. The ranging device should be capable of ranging to a distance of at least 1000 feet, with an optimum accuracy of $\pm$ 1 foot in 1000 feet, but with an acceptable accuracy of $\pm$ 10 feet in 1000 feet. An accuracy of $\pm$ 3.4 minutes of arc for azimuth and vertical angle readings is also desirable, but an accuracy of $\pm$ 34.0 minutes of arc is acceptable. These accuracy values are based upon traverses from the LEM to a maximum distance of about 1000 feet, and upon a mapping scale chosen to be somewhere between 1:480 and 1:1200. An

smallest object that can be shown on a map scale of 1:480.

An imaging system should be attached to the periscope so that distances and elevations can be obtained after return to Earth. The precision stated above can be attained by monoscopic comparator or phototheodolite methods. Obscuration of the nearby lunar surface by the top of the LEM, and restriction of the base of the optical range finder to some practical length, would probably prohibit photogrammetric compilations from stereo pairs taken through the periscope; these parts, however, would be useful for geologic and geomorphic interpretations on Earth by photogeologic methods.

Probably the best arrangement for using the periscope as part of a photogrammetric system would be the placement of clips for a compatible imaging system around the base of the LEM descent stage from which a near-ground panorama could be obtained. These photographs could be used with panoramic photographs taken through the periscope for photogrammetric compilation, and would have a vertical base on the order of 15 feet. With this system, photogrammetric measurements with reasonable accuracy could be made in the area between 25 and 300 feet from the LEM depending largely on the imaging, periscope and photogrammetric compilation systems employed.

An automatic tracking device that would keep the astronaut on the surface within view of the periscope is desirable. An imaging system connected to the periscope would then provide surveillance of the surface work being conducted. In addition, the man in the LEM could view the man on the surface at any time without first searching for his position. An automatic readout device for continuous transmission of range, bearing, and vertical angle information to Earth would permit data compilation during the mission. This could be done most rapidly by feeding the information through a computer and compiling the map with an X-Y plotter, using range and elevation and azimuth angles with respect to the LEM.

An optical- and stadia-ranging periscope capable of 2X/30°, 4X/15°, and 8X/7½° magnification and field of view is being constructed by the Branch of Astrogeology. The periscope will rotate through 360° and tilt from -15° to +45°, and will have an optical range finder with a 28" base. This periscope is being designed for scientific mission development studies for both Apollo and post-Apollo missions. Its purpose is to familiarize the geologists involved with the constraints imposed by a periscope during the monitoring of lunar field work, and to provide a firm basis for recommendations concerning the functional specifications for a periscope to be used in geologic exploration on the Moon.

LUNAR FIELD GEOPHYSICAL METHODS

Introduction

Time and information surveys conducted at six test sites comprised the initial phase of the Lunar Field Geophysical Methods study. The test sites were on the Kana-a lava flow, S. P. lava flow, and Bonito lava flow, all in northern Arizona; and the South Coulee lava flow and Ash Flats cinder ash at Mono Craters, and Bishop Tuff, welded tuff area, all in California.

The field surveys were conducted to determine the amount of time and effort required to collect geophysical data, evaluate its scientific usefulness, and determine potential problems inherent in terrestrial geophysical methods when applied to lunar exploration. The six test sites afforded a variety of terrains similar to expected lunar terrains.

Gravity meter and magnetometer traverses were laid out and surveyed for location and relative elevations of the instrument stations. The traverses varied in length from 1000 to 2000 feet and represented typical geophysical traverses across the given area rather than the roughest or smoothest area available. Two-hundred foot segments of four traverses were surveyed for elevations in two-foot increments to enable a study of terrain difficulty. The portable seismic tests were conducted along the gravity meter and magnetometer traverses but were not surveyed.

Operation of the three instruments used were divided into individual steps and 2 to 3 were timed step-by-step through the complete traverse or operation performed. Total times, means and standard deviations were computed for each test and the results have been tabulated and graphed. The more significant results are included in this report and the accompanying documentary film. Gravity meter traverses at Kana-a, S. P., and Bonito flows were rerun to determine the effect of operator experience on traverse time. Data were tabulated and graphed for evaluation of its usefulness in short traverses. Gravity meter, magnetometer, scintillator and portable seismic operations were recorded on film, some of which accompanies this report.

Progress to Date

Approximately two-thirds of the planned time and information studies for the Lunar Field Geophysical Methods project are now com-

each operation, data quality, operator experience, terrain difficulty and usefulness of data. The portable seismograph study of times required for each operation, and terrain difficulty are now complete. The magnetometer study is complete for terrain difficulty and partially complete for times required for each operation. The operation of the scintillation counter is similar to that of the magnetometer, therefore the scintillation counter will be used only in those areas where deposits of radioactive materials are known or suspected to occur.

Gravity Meter Tests

Instrument

A Worden Master gravity meter was used for the gravity studies. This gravity meter is a sensitive spring balance system encased in an insulating vacuum flask which incorporates a low power heating element to protect the gravity meter from temperature changes. This meter is capable of indicating changes in gravity of approximately one unit in one hundred million. It is set on three level screws built into the meter base to enable fine adjustments in the leveling of the instrument; a longitudinal level and a transverse level are built into the top of the meter. The meter is set on a 2½ pound tripod surface plate containing a bullseye bubble for rough leveling. The meter alone weighs 8 pounds. The meter is equipped with a visual-readout turns-indicating dial and a reset control to allow a wide reading range and the viewing system consists of an eyepiece assembly and an illuminated reticle inscribed with reference lines.

The meter is read by the observer looking through the microscope eyepiece at a line of light reflected from the beam to the reticle. The turns-indicating dial is adjusted until the beam is centered on the reticle center line or in null position and then the dial is read in hundreds, tens, units, and tenths. The dial readings are multiplied by a conversion factor to change the dial readings to milligals.

Method of Operation

The operation of the gravity meter was divided into the following six basic steps:

Step 1: travel.--The gravity meter in the carrying case is carried in one hand by the operator and the tripod is carried in the other hand. In our tests, the operator walked one hundred feet to the first gravity reading setdown.

Step 2: setdown.--The operator kneels on one knee, sets the carrying case on the ground, then the tripod surface plate is emplaced in or on the surface of the ground and roughly leveled utilizing the bullseye level in the center of the plate. The carrying case is opened and the gravity meter is carefully lifted out of the case, and placed on the tripod surface plate. The interior viewing light is turned on and the meter is roughly leveled by centering it on the plate.

Step 3: level.--The operator levels the gravity meter by adjusting [illegible] until bubbles in the longitudinal and transverse levels [illegible]

Step 4: adjust.--The operator looks through the microscope eyepiece and adjusts the beam until it is in null position by turning the turns-indicating dial with his right hand.

Step 5: read and reread.--The operator reads the turns-indicating dial, turns the dial counter clockwise one-half turn, looks into the eyepiece again, readjusts the beam to a null position, and rereads the turns-indicating dial. If the reading is within three-tenths dial divisions (about 0.03 mgal) of the first reading, this step is completed. If not, the beam is readjusted and the dial reread until a given reading is repeated within three-tenths of a scale division.

Step 6: pickup.--The operator turns off the viewing light, picks up the gravity meter in both hands, places the meter in the carrying case and closes the case. He then picks up the tripod surface plate in one hand and the carrying case in the other and stands up to walk to the next gravity station.

These six steps are then repeated by the number of gravity stations on the traverse. An observer times the steps and records the readings.

Four operators were used on the various gravity meter tests. None were initially experienced in the operation of gravity meters. No. 1 was 36 years old, 6 feet 2 inches tall and weighed 195 pounds. He performed 2 tests. No 2 was 44 years old, 5 feet 8½ inches tall and weighed 175 pounds. He performed 5 tests. No. 3 was 26 years old, 5 feet 7 inches tall and weighed 150 pounds. He performed 14 tests. No. 4 was 19 years old 5 feet 11½ inches tall and weighed 190 pounds. This operator performed 1 test. A total of 22 time and information tests were performed with the gravity meter.

Figure 8 shows mean times required by Operator No. 3 for each step of the gravity meter operation on each of the flows studied. It is interesting to note that the highest times were required for all steps on the South Coulee flow, with the exception of travel times, which were slightly greater on Bonito flow. The instrument operators believe that slower travel times on Bonito flow were caused by the cautious manner in which the operator traversed the jagged lava of this flow.

Figure 9 shows the standard deviation of times required for Operator No. 3 for each step of the gravity meter operation. Data presented

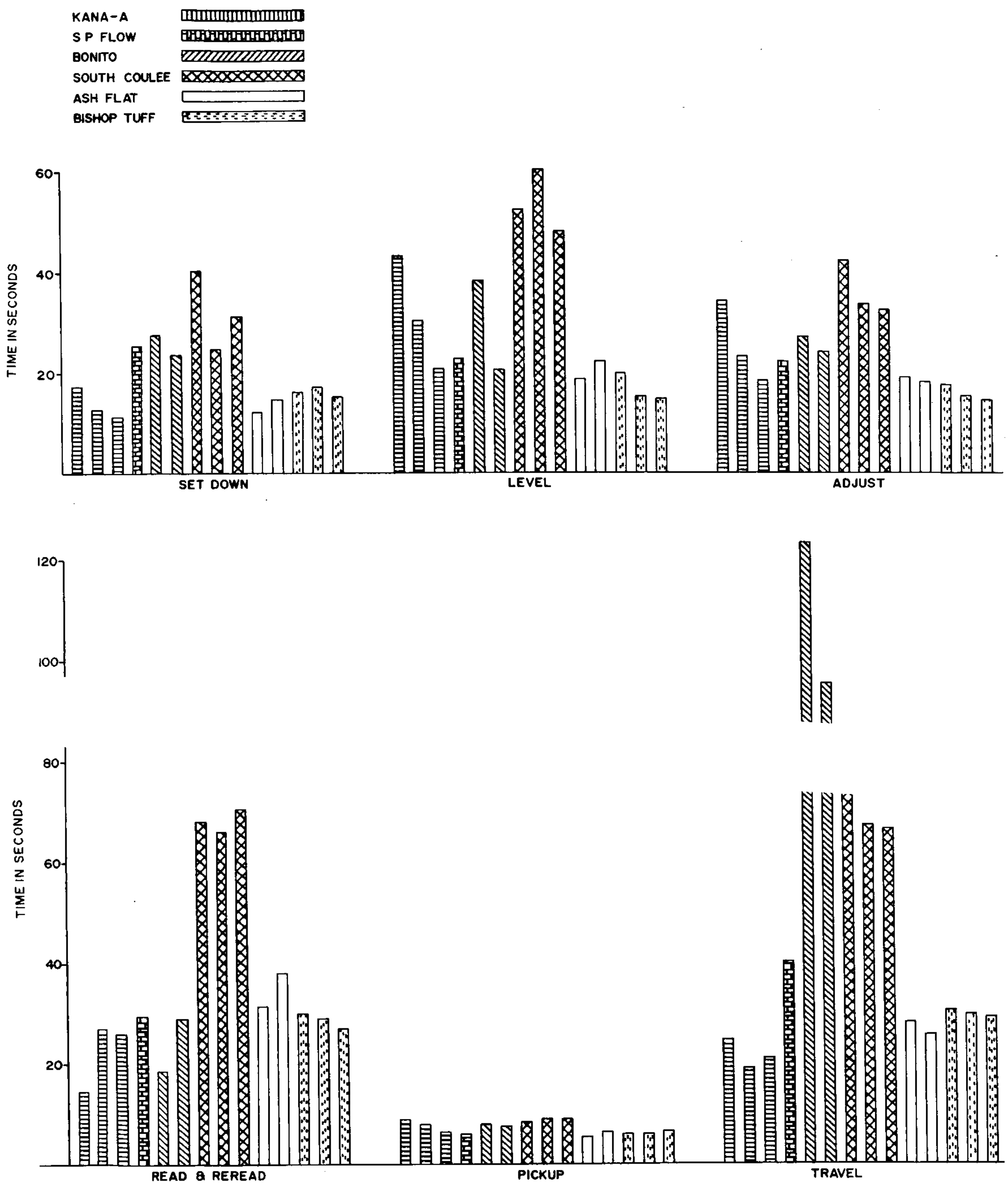


Figure 8.--Mean times for various operations of gravity meter by Operator No. 3

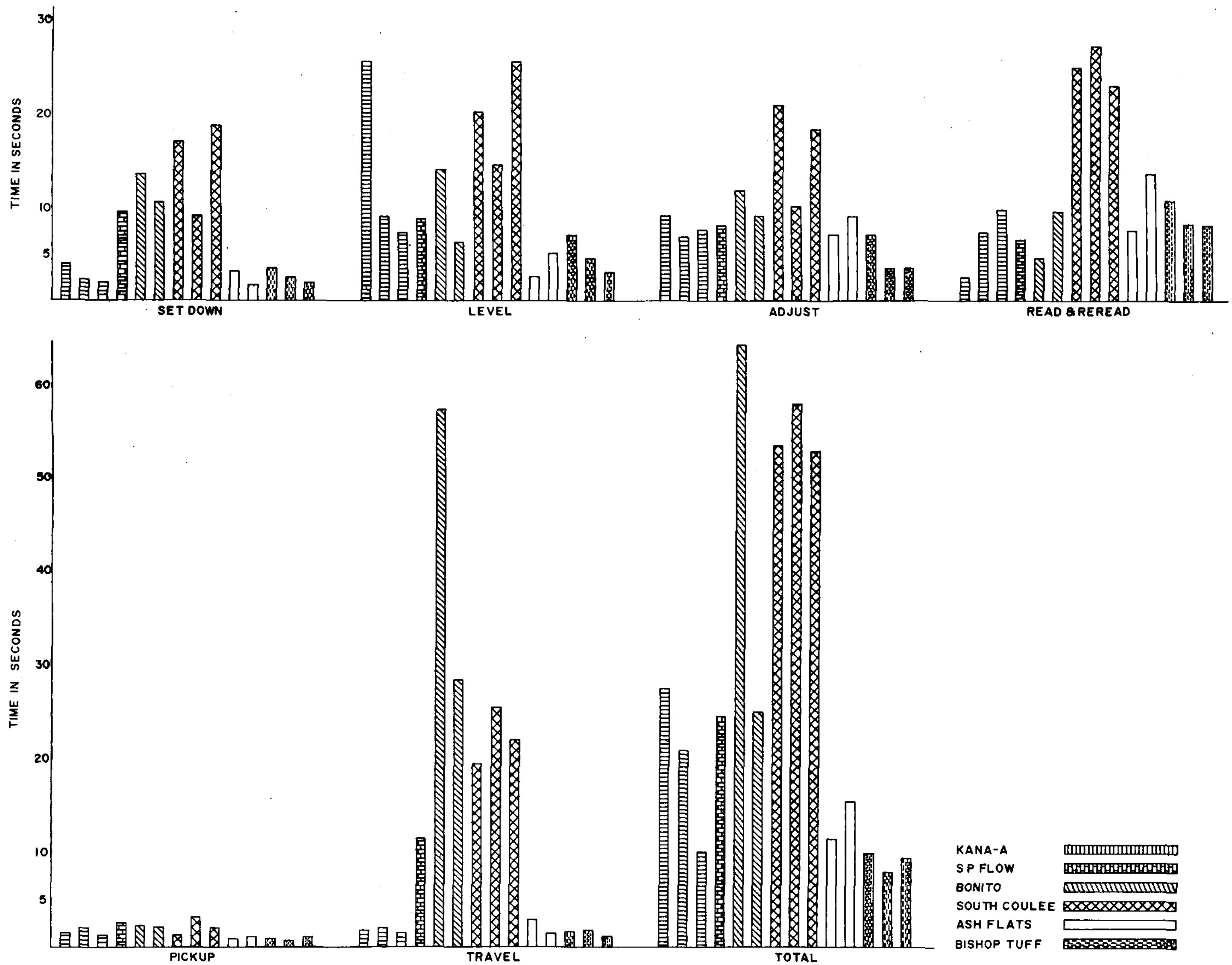


Figure 9.--Standard deviation of times for various operations of gravity meter by Operator No. 3.

below suggest that it is possible to predict the roughness of the terrain and correlate the roughness of the terrain with the times required for traversing by an astronaut. During planning of the actual missions it would be well to take the average time across similar terrain on the Earth and add one or more standard deviations to this average time to insure that the astronaut will be able to satisfactorily complete his mission.

Times Required for Each Operation

The times required by the various operators at the different sites were summed and averaged; this data appears in Table 6.

As is seen in Table 6, the average six-step total operation time varied from 104.2 seconds on Kana-a flow to 452.7 seconds on S. P. fl[illegible]

[illegible] difficulty but because of one inexperienced operator who ran his first gravity traverse on the flow. Neglecting his long operation times on the flow, the data shows that the next longest total average time is 238.7 seconds.

Figure 10 shows comparison of travel time to total operation time for the six sites tested.

Data Quality

Accurately reading the gravity meter requires experience and finesse on the part of the operator. The alignment of the hairline in the null point, the correct sensing of the hysteresis of the beam, and the leveling all contribute to a good reading. The failure of

Table 6.--Average gravity meter operation times for various operators

Date	Place	Operator	Set Down	Level	Adjust	Read & Reread	Pickup	Travel	Total
8/20/64	Kana-a Flow	1	16.9	38.1	32.0	17.0	8.4	23.7	136.1
8/20/64	"	3	17.2	43.0	34.2	14.7	9.1	24.3	142.5
8/26/64	"	3	12.4	30.0	24.0	27.2	8.0	19.1	120.8
8/26/64	"	4	11.8	35.8	26.9	27.1	9.1	20.7	131.5
11/2/64	"	3	11.5	20.5	18.7	25.9	6.4	21.1	104.2
9/3/64	SP Flow	1	31.4	66.4	26.3	50.6	11.9	52.1	238.7
9/4/64	"	2	40.2	201.0	51.4	82.9	9.9	67.1	452.7
11/5/64	"	2	39.8	39.9	34.5	45.2	8.0	46.4	214.0
11/5/64	"	3	25.5	22.7	22.1	29.6	6.2	39.8	146.1
9/8/64	Bonito	2	38.7	91.4	39.2	28.8	9.3	105.4	313.0
9/8/64	"	3	27.3	38.0	26.9	18.5	7.8	122.9	249.4
11/2/64	"	2	34.8	34.4	37.3	30.1	8.0	102.3	246.7
11/2/64	"	3	23.3	20.7	23.4	29.6	7.1	95.1	195.7
10/1/64	South Coulee	3	40.2	52.1	43.3	68.7	8.3	75.4	288.3
10/1/64	"	3	24.5	60.0	33.4	65.9	9.3	66.8	260.9
10/1/64	"	3	30.9	47.4	32.5	70.1	9.1	65.8	256.0
10/7/64	Ash Flats	3	11.7	18.4	19.0	31.4	5.8	28.4	115.0
10/7/64	"	3	14.6	22.0	18.0	38.1	6.1	25.5	124.6
10/7/64	"	2	21.0	27.2	26.9	64.9	7.0	26.8	171.2
10/8/64	Bishop Tuff	3	16.0	19.8	17.4	29.9	5.8	30.7	119.8
10/8/64	"	2	16.8	15.1	15.4	29.3	5.6	29.1	111.7
10/8/64	"	3	14.8	14.9	14.7	27.4	6.4	29.0	107.5

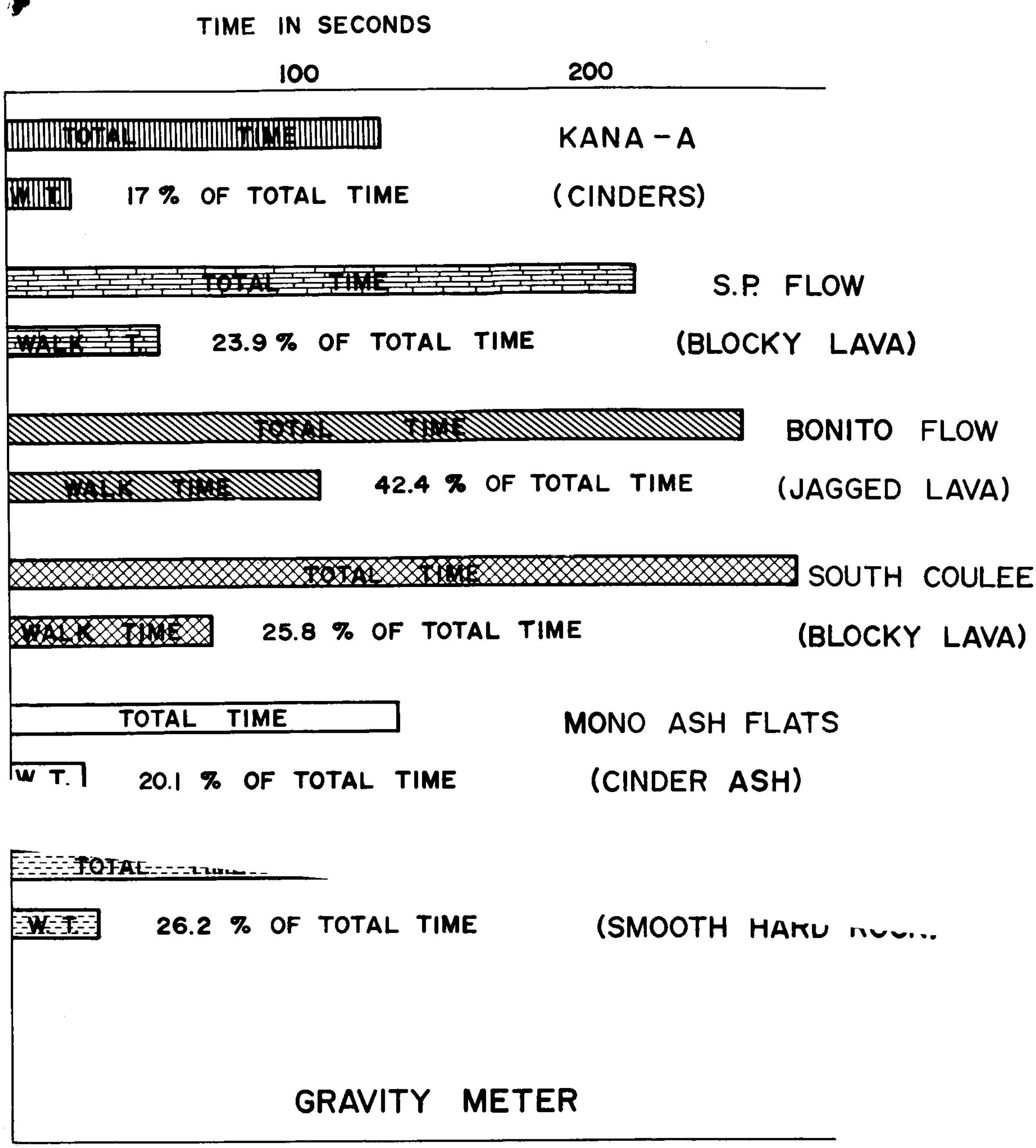


Figure 10.--Comparison of walking time to total operation time for gravity meter operations

the operator to obtain good readings is reflected in the spread of values which he obtains at any given site. The spread of values were evaluated (see figure 11) for each station to check the operator's overall performance and to evaluate the data. The graphs (figure 11) show the average spread between two readings, X_1 and X_2, taken at each station. At those stations where more than two readings were taken, each interval was assumed equally likely and all intervals were included in the sum. For example, if the meter was read three times and values X_1, X_2, and X_3 were obtained, then intervals $X_1 - X_2$, $X_1 - X_3$, and $X_2 - X_3$ were all included in the data for analysis. In the case of N readings, the number of intervals equals the number of combinations of N things taken two at a time. Each interval was weighted equally in the final summation.

It can be seen from the data in figure 11 that the intervals between readings generally decrease with time. However, it should be noted that the terrain on the South Coulee was very difficult to cross whereas the terrain on the Bishop Tuff was flat and unobstructed. Consequently, some of the improvement in data may be due to the better terrain and the better opportunity for the operator to find a good seat for the tripod and the gravity meter. Although the data are inconclusive, it appears that some of the proficiency gained during the intensive field work in eastern California (South Coulee, Ash Flats, and Bishop Tuff sites) as reflected by decreased spreads of values, was lost during the period of time before the gravity surveys of S. P. flow and Bonito flow.

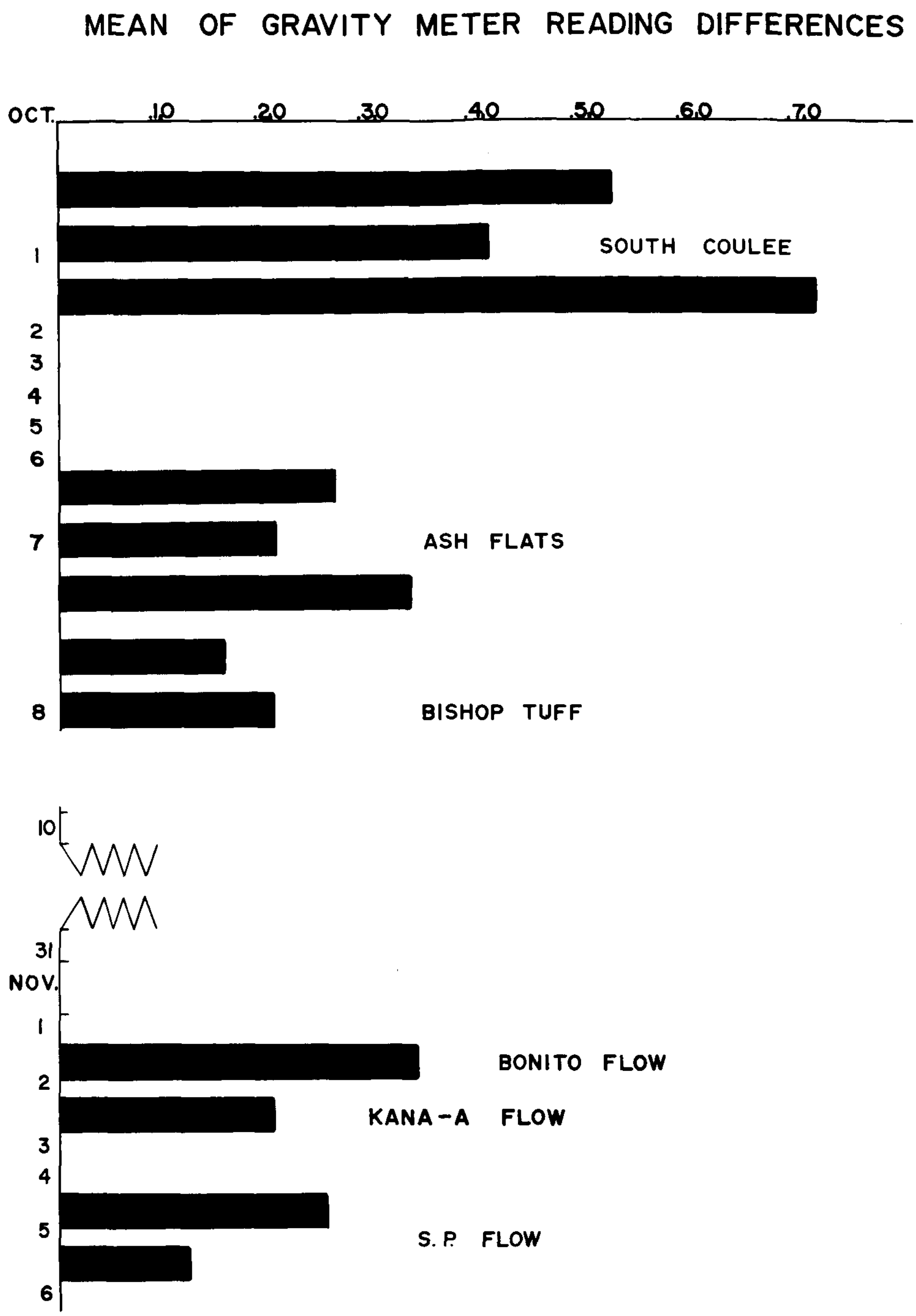


Figure 11.--Average spread between pairs of readings observed on 13 traverses between October and November, 1964

Operator Experience

The operators tested all showed improvement in total times required for each operation and in data quality. Operator No. 3 ran the greatest number (14) of gravity meter tests. Table 7 shows mean times required to perform the various steps at all six sites; figure 12 shows the step-by-step and total time improvement experienced by Operator No. 3 on Bonito and Kana-a flows. Figure 13 shows the improvement experienced by Operator No. 2. Additional tests at these sites in the future will reveal the total amount of improvement possible. These data show reductions in total times ranging up to 28 percent and also that time required for leveling is where the greatest improvement takes place. The experience factor influences different people in different ways; for example, Operator No. 3 improved his travel time by 27.8 seconds on Bonito flow while Operator No. 2 improved his by only 3.1 seconds. However the greater number of traverses performed by Operator No. 3 may explain some of this difference. Detailed studies at one site with an inexperienced operator should reveal a rapid initial improvement with a gradual reduction as the operator becomes experienced.

Terrain Difficulty

Four of the six sites were surveyed along 200 foot segments of the traverses with elevations determined at intervals of 2 feet. These profiles are shown in figures 14, 15, 16, and 17. The Bonito flow, in the opinion of the operators, is the most difficult for operations. This opinion is confirmed by the travel times which show that 42 percent of the total time required for operation was required for

Table 7.--Mean times required to perform various steps of gravity meter operation on 14 traverses by Operator No. 3

Date	Place	Set Down	Level	Adjust	Read & Reread	Pickup	Travel	Total
8/20/64	Kana-a	17.2	43.0	34.2	14.7	9.1	24.3	142.5
8/26/64	"	12.4	30.0	24.0	27.2	8.0	19.1	120.8
9/8/64	Bonito Flow	27.3	38.0	26.9	18.5	7.8	122.9	249.4
10/1/64	South Coulee	40.2	52.1	43.3	68.7	8.3	75.4	288.3
10/1/64	"	24.5	60.0	33.4	65.9	9.3	66.8	260.9
10/1/64	"	30.9	47.4	32.5	70.1	9.1	65.8	256.0
10/7/64	Ash Flats	11.7	18.4	19.0	31.4	5.8	28.4	115.0
10/7/64	"	14.6	22.0	18.0	38.1	6.1	25.5	124.6
	Tuff							
10/8/64	"	16.8	15.1	15.4	29.3	5.6	29.1	111.7
10/8/64	"	14.8	14.9	14.7	27.4	6.4	29.0	107.5
11/2/64	Kana-a	11.5	20.5	18.7	25.9	6.4	21.1	104.2
11/2/64	Bonito	23.3	20.7	23.4	29.6	7.1	95.1	195.7
11/5/64	S.P.	25.5	22.7	22.1	29.6	6.2	39.8	146.1

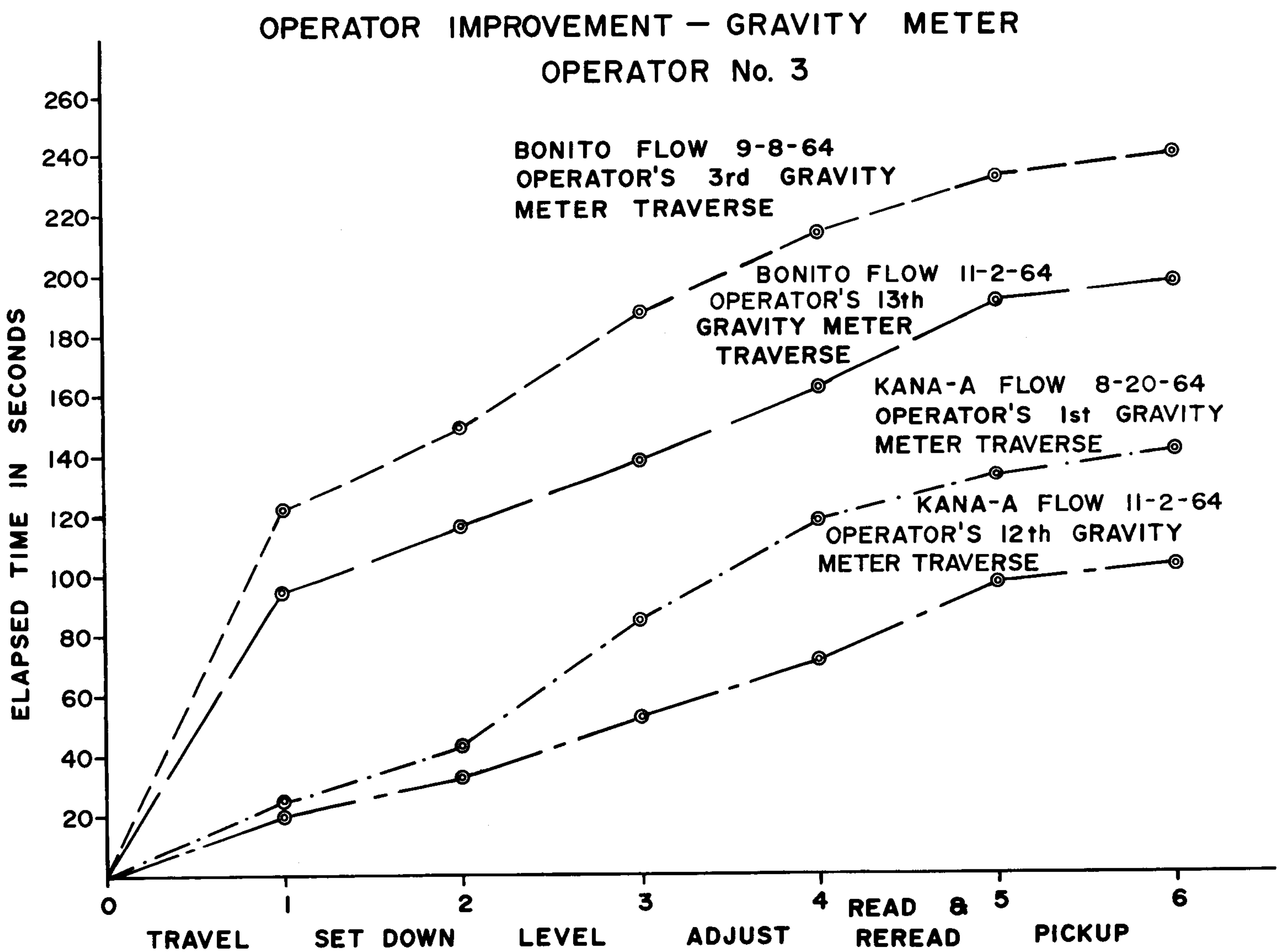


Figure 12.--Improvement of times for various operations of the gravity meter with increased operator experience, Operator No. 3

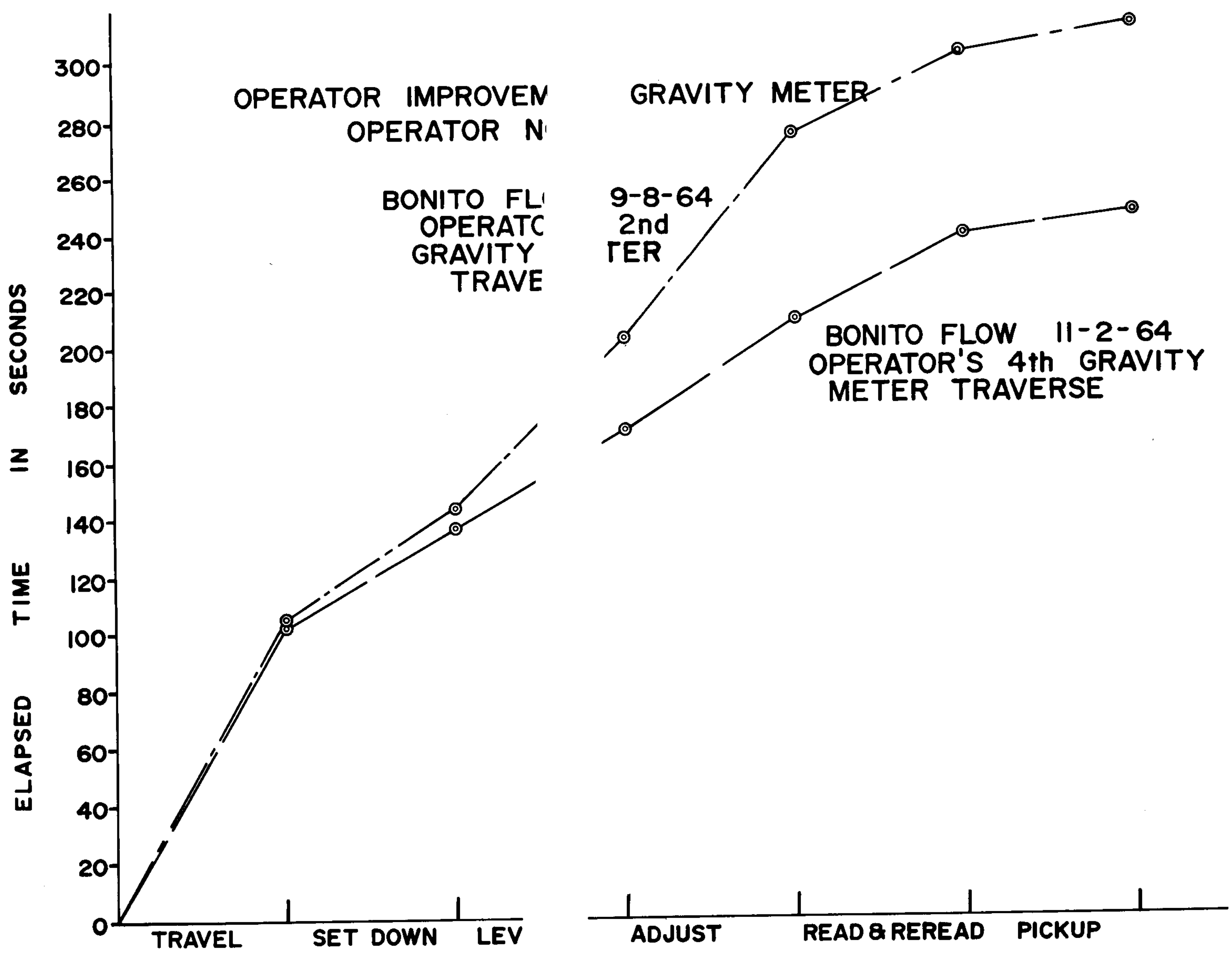


Figure 13.--Improvement of for various operations of the gravity meter with incr operator experience, Operator No. 2

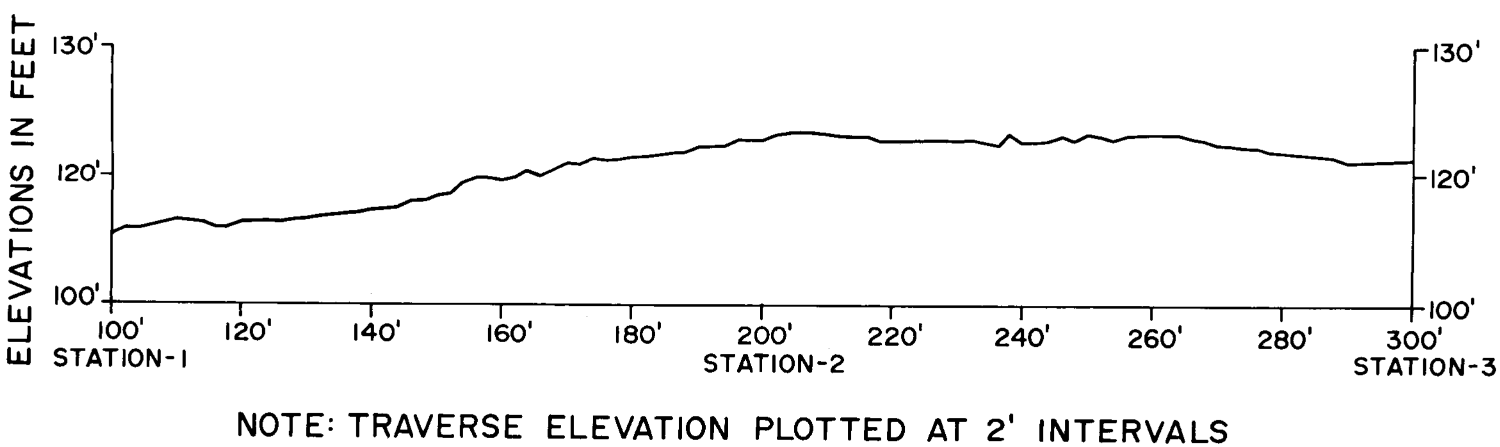
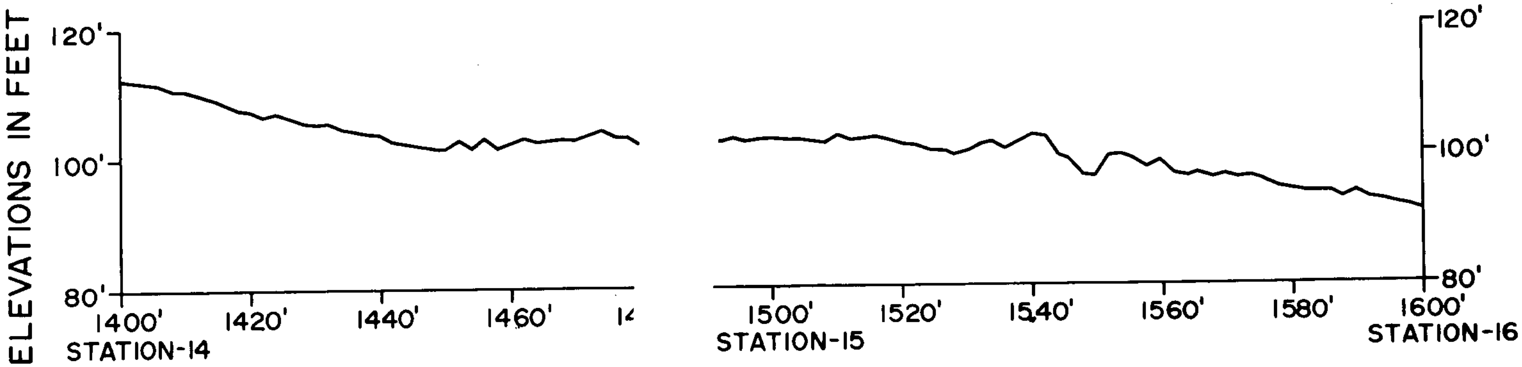


Figure 14.--Topographic profile from South Coulee traverse



NOTE: TRAVERSE ELE' ...)N PLOTTED AT 2' INTERVALS

Figure 15.--Topographic ... ile from S.P. traverse

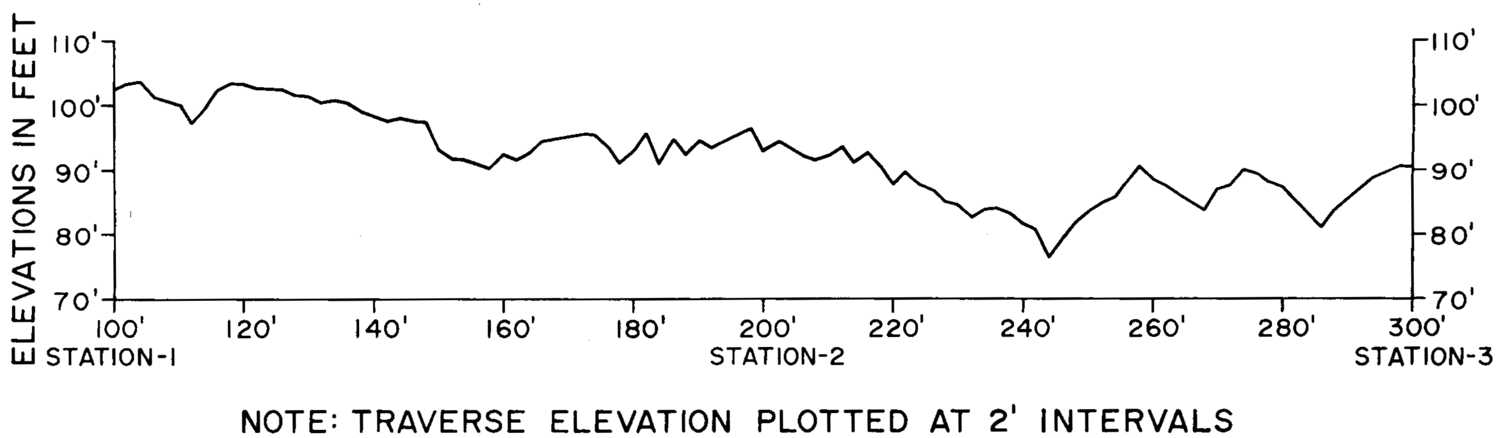


Figure 16.--Topographic profile from Bonito Flow traverse

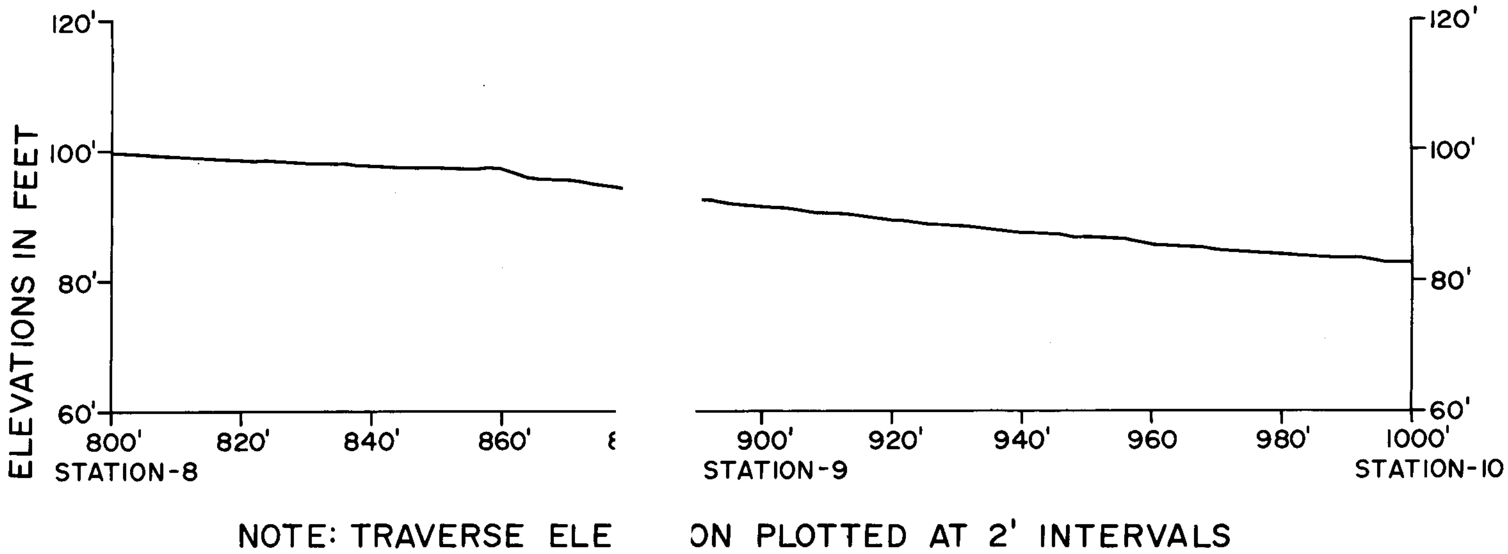


Figure 17.--Topogra profile from Kana-a traverse

walking. The operators feel that the treacherous footing on the loose pumice blocks of the South Coulee make that traverse more difficult than the traverse across the S. P. flow. Data of table 6 and figure 10 tend to confirm these impressions made by the operators during the traverses. The traverses across Ash Flats and the Bishop Tuff were not surveyed because both traverses are relatively flat. However, the footing is solid and relatively unobstructed on the Bishop Tuff but consists of small fragments of pumice and ash across Ash Flats. It would seem logical to expect that the travel time across the Bishop Tuff would be somewhat less than the travel time across Ash Flats instead of the faster travel time observed on Ash Flats. It might be, however, that longer traverses would show shorter average times on the Bishop Tuff as fatigue was an important factor during operations on the loose material of Ash Flats.

It is interesting to note that downhill time on S. P. flow averaged 11 seconds longer than uphill time. This is thought to be caused by the uncertain footing on this flow. The blocks of lava on S. P. flow are generally small and turn easily underfoot. For this reason, the gravity meter operator moved more cautiously when making the downhill traverse than on the uphill traverse.

In an effort to derive a quantitatively significant relationship between terrain difficulty and average travel times, the mean value of the slopes and the standard deviation of the slopes of the 2 foot segments of traverses were computed and compared with the average walking times. These relationships are shown in table 8. These data show that as the standard deviation of slope segments increases, the average walking time increases and that the ratio of the standard deviations of the slope segments to the average walking times is constant within a factor of 3 in the four sites which we investigated. More data will be required to increase the precision with which the walking time can be estimated from the standard deviation of the slope segments, but the tentative correlations of slope segments to the walking time appears significant because the standard deviation of the slope segments is a parameter which can be calculated from good photography from an aircraft or an orbiter.

If additional data confirm our tentative conclusions concerning the correlation of the slope segments and the walking time, then the

be photographed and the mean value of the slopes and the standard deviations of small segments of the slopes such as we have used here can be calculated along with traverses which the astronauts will cross during the landings. Depending on the variability of the data determined from the terrestrial traverses, it should be possible to estimate the time required by the astronaut to traverse a given segment of the Moon's surface, to calculate the standard deviation of the slope segments, and to obtain a precise estimate of the time which it will require the astronaut to cross an area of the lunar surface. By allowing the anticipated time plus one or two standard deviations of the terrestrial time, an adequate safety factor will be introduced to

Table 8.--Mean slopes, standard deviation of slopes of 2 ft. segments of traverses, average walking times, and ratios of standard deviations of slope segments to average walking time

Test Site	Direction	Mean Slope	Standard Deviation Slope	Average Walking Time	Ratio of Standard Deviation of Slope to Average Walking Time	Number of Tests
Kana-a	Downhill	-.09	.06	40.2	.0015	3
South Coulee	Downhill	-.04	.20	71.8	.0028	1
S.P.	Downhill	-.11	.30	88.1	.0034	2
Bonito	Downhill	-.02	.82	215.4	.0038	2
Kana-a	Uphill	.09	.06	40.9	.0015	2
South Coulee	Uphill	.04	.20	75.6	.0026	2
S.P.	Uphill	.11	.30	77.1	.0039	2
Bonito	Uphill	.02	.82	273.7	.0030	2

insure that the astronaut will have sufficient time to complete his mission and return to the LEM.

Usefulness of Data

All gravity meter traverses were surveyed for station elevations and the gravity anomalies computed for each traverse. Figure 18 shows the traverse profile across Ash Flats and the Bouguer anomalies as observed on three tests on October 7, 1964; figure 19 shows similar data obtained on the Bishop Tuff on October 8, 1964; figure 20 shows data collected on the South Coulee on October 1, 1964; figure 21 shows data from S. P. flow; figure 22, data from Bonito flow; figure 23, data from Kana-a flow. These data are relative to an arbitrary base value, hence the values in milligals along the abscissa are relative.

[illegible] and Bishop Tuff are very small, a fact which is consistent [illegible] sites. It is doubtful that these data would justify operation of a gravity meter on similar areas of the lunar surface. The Bouguer anomalies observed on the four lava flows, however, are somewhat greater, ranging from 1 to 2 milligals in magnitude. Expectation of anomalies at this magnitude might justify operation of a gravity meter over areas of the lunar surface. However, it should be noted that the average time required to obtain a reading and walk the distance between the stations, which are 100 feet apart, is about four minutes. Hence, it required an unencumbered man operating the gravity meter across the Earth's surface approximately forty minutes to obtain

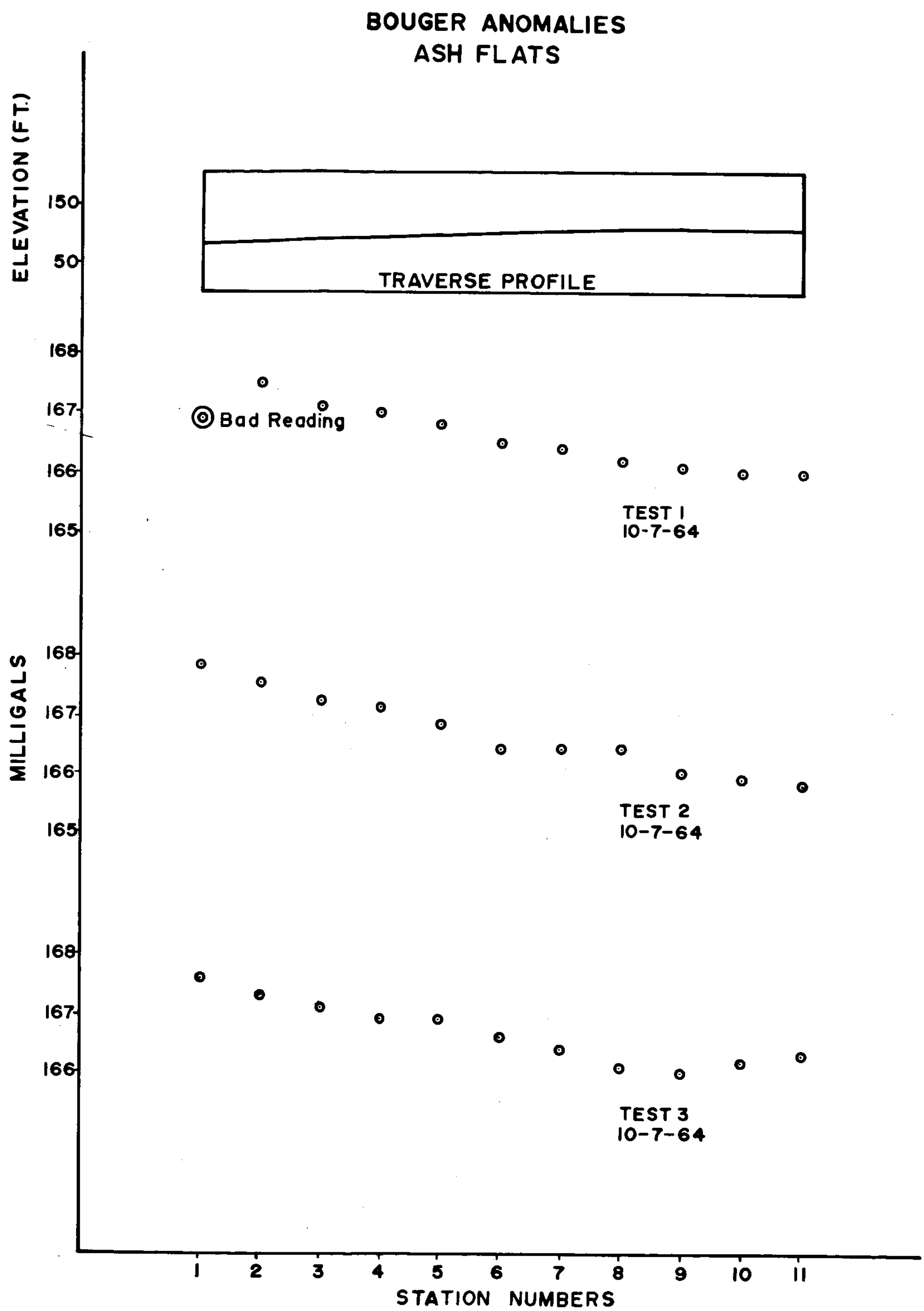


Figure 18.--Bouger anomalies and traverse profile across Ash Flats, Mono Crater, California.

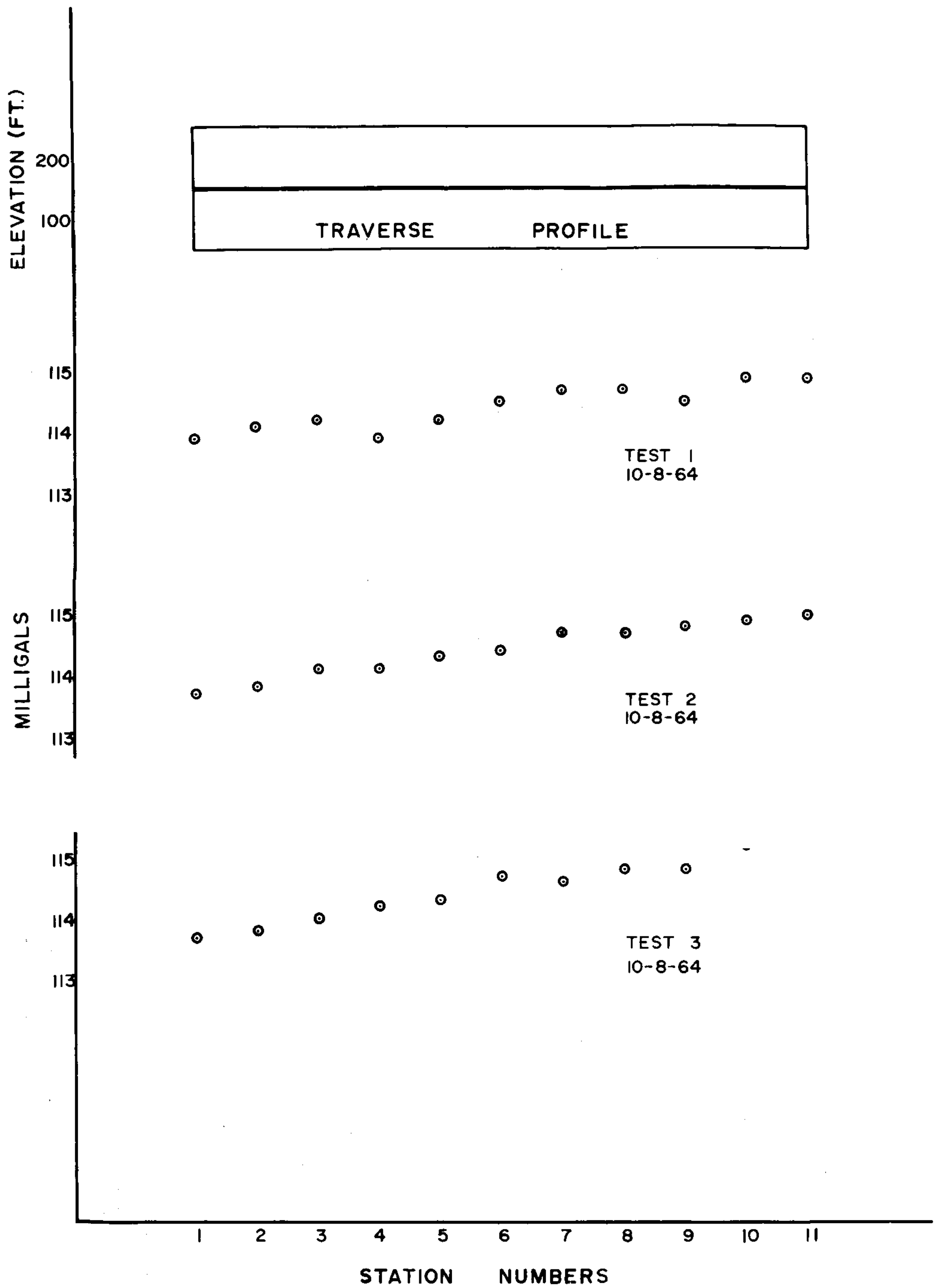


Figure 19.--Bouger anomalies and traverse profile across the Bishop Tuff, Bishop, California.

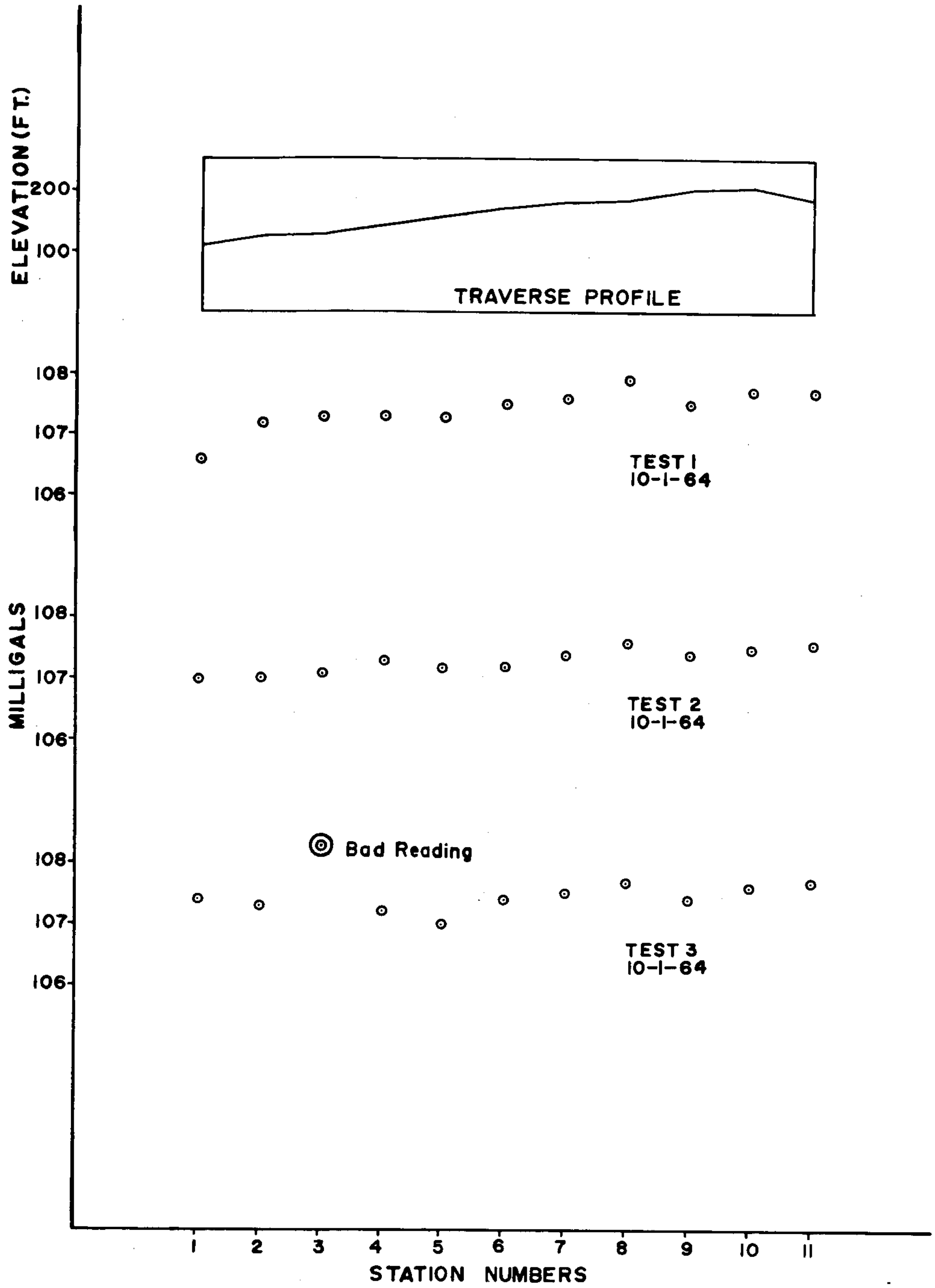


Figure 20.--Bouger anomalies and traverse profile across South Coulee, California.

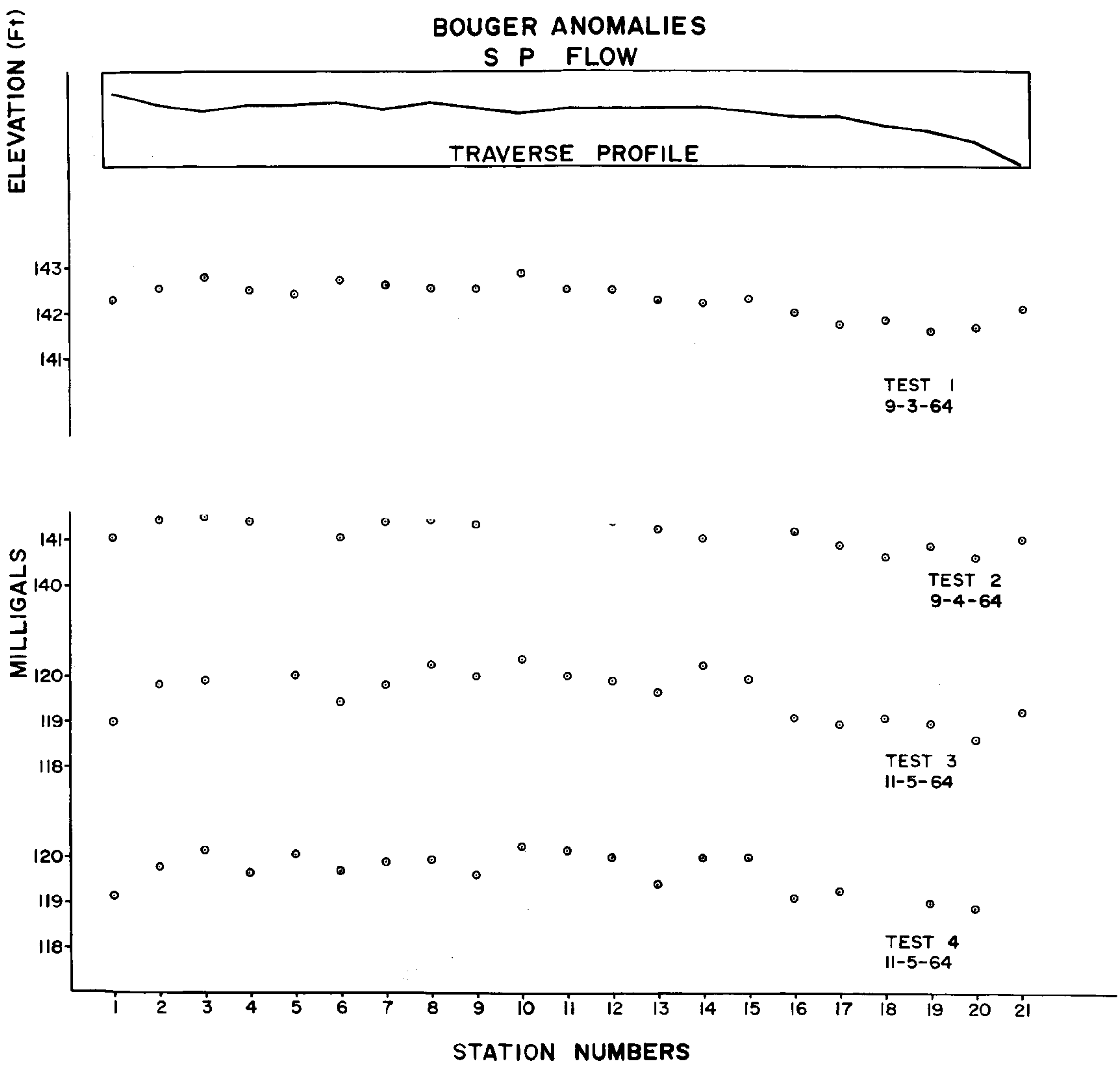


Figure 21.--Bouger anomalies and traverse profile across S.P. lava flow, Arizona.

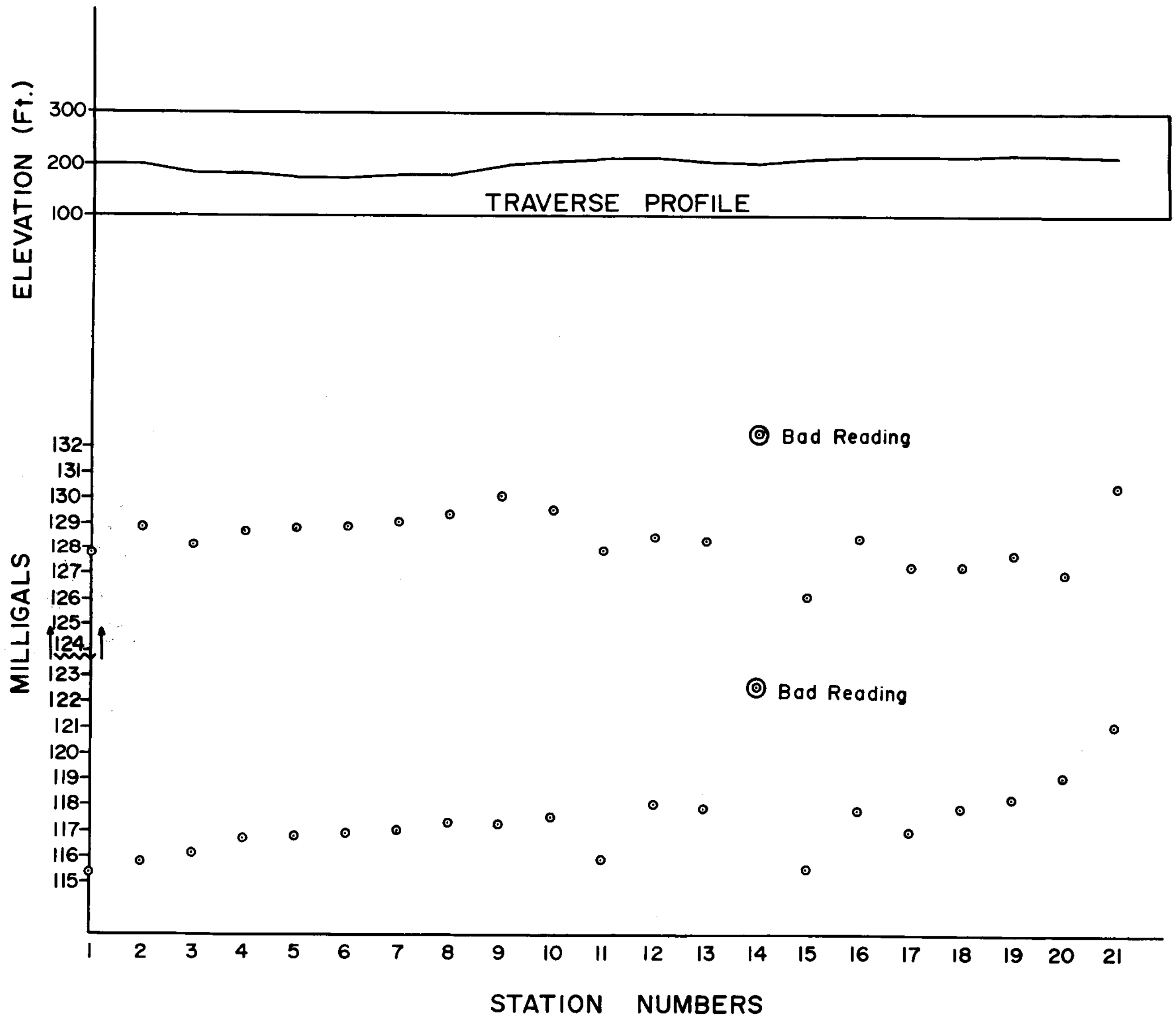


Figure 22.--Bougér anomalies and traverse profile across the Bonito lava flow, Arizona.

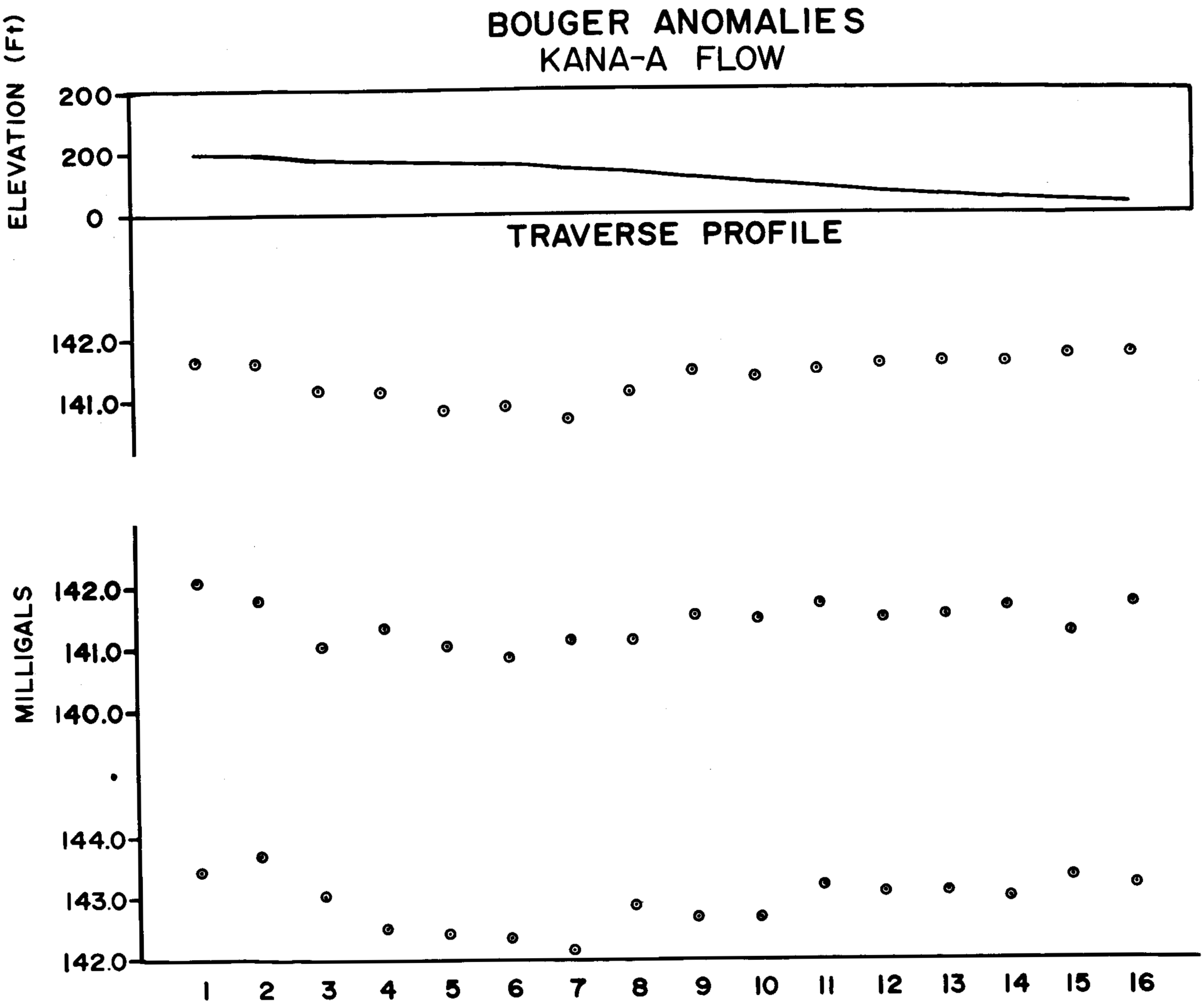


Figure 23.--Bouger anomalies and traverse profile across the Kana-a lava flow, Arizona.

ten readings. A very optimistic estimate of the time required for an astronaut to obtain the same amount of data across similar terrain on the lunar surface would be eighty minutes, or twice the time required to obtain the data on the terrestrial terrain. Therefore, it is concluded that field surveys with a gravity meter during the early Apollo missions is not justified unless a special problem exists which can be resolved with the gravity meter better than any other technique.

These adverse recommendations concerning gravity meter field surveys do not however detract from the usefulness of measurements of absolute gravity on the lunar surface.

Portable Seismograph Tests

Instrument

The portable seismograph used on the time and information studies consisted of 12 transistorized amplifiers with adjustable gains, a capacitor discharge type blaster, twelve data traces and a shot break trace, 12 galvanometers, a Polaroid film holder, and batteries for power. All components were enclosed in an aluminum case. Total weight of the seismograph was 25 lbs. A 710-foot geophone cable on a portable aluminum reel weighed 24½ lbs., and the 12 geophones weighed 18 lbs. collectively, the total weight of the system was 67½ lbs.

This meter was chosen for the test because it is one of the smaller, lighter, and least complicated seismographs commercially available today.

The recording interval timer provides a photographic record of seismic waves on an accurate time base. An internal light source projects a light beam onto a mirror in each galvanometer from where it is reflected by a rotating mirror onto the film in the Polaroid film holder. When a signal voltage from a geophone is applied to the galvanometer, a rotating mirror deflects the light beam proportionally providing a sweep of the galvanometer traces along the record. The rotating mirror is actuated by a pendulum which also initiates the timing interrupter, and operates the micro-switch that discharges the blaster capacitor into the cap line. The timing interrupter interrupts the galvanometer traces at ten millisecond intervals. Duration of recording time may be varied by adjusting the center of gravity of the pendulum.

vanometer lamp, energizes the holding coil which cocks the vibrating reed of the timing interrupter, and charges the blaster capacitor. A neon lamp Ready indicator connected across the blaster capacitor lights to indicate when the instrument is ready to fire the cap. The Fire switch is depressed with the Arm-Align switch held in Arm position and the Ready indicator lamp lit. Depressing the Fire switch releases the pendulum, which initiates the timing interrupter, discharges the blaster capacitor, and starts the galvanometer sweep in motion.

The Polaroid film is then developed to obtain the photographic record of the seismic wave.

Method of Operation

The portable seismograph requires two men for its operation. The first man, hereafter called Operator No. 1, is primarily an instrument operator. The other man, hereafter called Operator No. 2, is primarily the geophone cable handler.

The operation consists of laying the geophone line, connecting the 12 geophones, setting up the interval timer, loading a cap into a charge of dynamite, connecting the cap to a shooting line, connecting the shooting line to the timer, loading the film in the Polaroid film holder, checking the geophone continuity, and firing the charge. After the film record is developed, Operator No. 1 carries the interval timer to the other end of the geophone line where Operator No. 2 had loaded a charge and strung the cap wire and shooting line back to the instrument station location. The interval timer is connected to the geophone cable, the charge is set off, the film developed, and the equipment picked up by the two operators to end the operation.

The individual steps are as follows:

Step 1.--Operator No. 1 - Pick up instrument, camera cable, ground wire, film, 2 geophones, charge, cap and shot line. Operator No. 2 - Pick up cable reel and put on truck, charge, cap, shot line, and 10 geophones.

Step 2.--Operator No. 1 - Set down instrument and open. Hook up geophone cable, camera cable, and ground. Operator No. 2 - Reel out geophone cable, dropping 1 geophone at takeout 3, 4, 5, etc. Double line back from takeout 12 to 11 and drop cable connector and cable reel.

Step 3.--Operator No. 1 - Carry cap, charge, shot line and 2 geophones. Drop geophone by takeouts 2 and 1. Pace 10 steps past end of takeout 1. Operator No. 2 - Walk back to 12 geophone and set charge, cap, and shot line on ground.

Step 4.--Operator No. 1 - Load charge and unreel cap wire. Operator No. 2 - Hook up geophone 12, 11, 10, etc. to 4. (Note: Number of geophones connected varies with roughness of the terrain.)

Step 5.--Operator No. 1 - Connect cap wire to shot line. Unreel shot line hooking up geophones 1 and 2 on way back to instrument. Connect shot line to instrument. Hook up geophones 3 and 4, etc. Walk back to instrument. (Note: Number of geophones connected varies with roughness of terrain.) Operator No. 2 - Walk back to geophone 12.

Step 6.--Operator No. 1 - Check entire geophone continuity 1 through 12, switch to normal, load film pack, pull film pack back, cock, arm, fire. Operator No. 2 - Pick up charge, cap and shot line. Pace 10 steps from geophone 12.

Step 7.--Operator No. 1 - Process film. Flip process lever. Pull film out. Count ten, pull cover off of film. Apply fixer. Flip process lever back to load. Operator No. 2 - Load charge and unreel cap wire.

Step 8.--Operator No. 1 - Disconnect geophone connector, camera cable, ground, shot line and close instrument. Operator No. 2 - Connect cap wire to shot line. Unreel shot line to geophone 11. Hook up shot line to instrument.

camera cable and

line.

Step 10.--Operator No. 1 - Set down instrument by geophone 11. Open and hook up geophone line, camera cable and ground. Check continuity. Switch to normal, load film pack, pull film pack back, cock, arm, fire.

Step 11.--Operator No. 1 - Process film. Flip process lever. Pull film out. Count ten. Pull cover off of film. Apply fixer. Flip process lever back to load.

Step 12.--Operator No. 1 - Disconnect geophone connector, camera cable, ground shot line and close instrument. Wind up shot line.

Step 13.--Operator No. 1 - Reel up shot line. Pick up 12 and 11 geophones.

Step 14.--Operator No. 1 - Pick up instrument, camera cable, ground and shot line. Carry instrument to end of line picking up geophones 10 through 1 on the way. Set down at end of line and reel up first shot line.

Times Required for Each Operation

The times required to conduct simple refraction seismograph surveys, ranged from a little less than 1,000 seconds to approximately 1,800 seconds in the sites that were studied during the report period (see figures No. 24 and 25). Times required to conduct the experiment over the cinders and lava of the Kana-a Flow, the cinders of the Mono Ash Flats, and the solid surface of the Bishop Tuff, were considerably less than the times required over the broken, brecciated, and fractured surfaces of S. P. Flow, Bonito Flow and South Coulee of the Mono Craters. Standard deviations of the total times (figures 24 and 25) are also greater over the rugged terrane of the lava flows and the South Coulee. The probability of duplicating the traverses over the Kana-a Flow, Mono Ash Flats, and Bishop Tuff within 100 seconds of the mean times is, therefore, high relative to the probability of duplicating the same operations within 100 seconds over the flows in the South Coulee. The operations performed by each operator were chosen so that total times required for each operator would be approximately the same. The initial assumptions concerning the times required for each operation appear to be valid for the easily traversable terranes, but in the difficult terranes Operator No. 2 required significantly more time to complete his operations.

Figures 26 and 27 show the step-by-step mean operation times for the six sites. Times required for most steps were relatively uniform for all locations. As might be expected, however, those steps requiring walking varied significantly between the easily traversable terranes

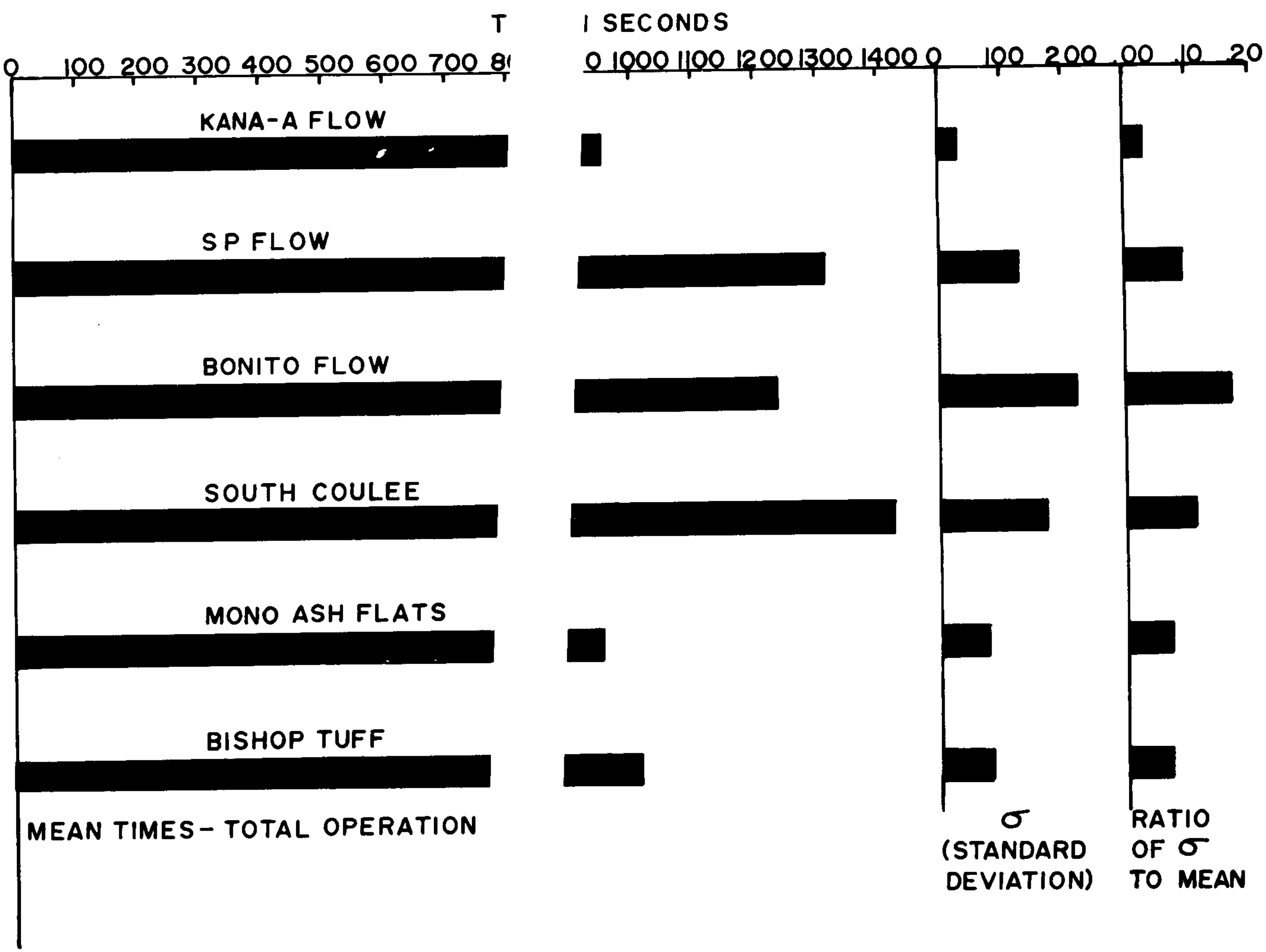


Figure 24.--Mean total oper: times, standard deviations, and normalized stan(leviations (ratio of standard deviations to m(for Operator No. 1 on six sites. Operator No. 1 : e seismograph operator.

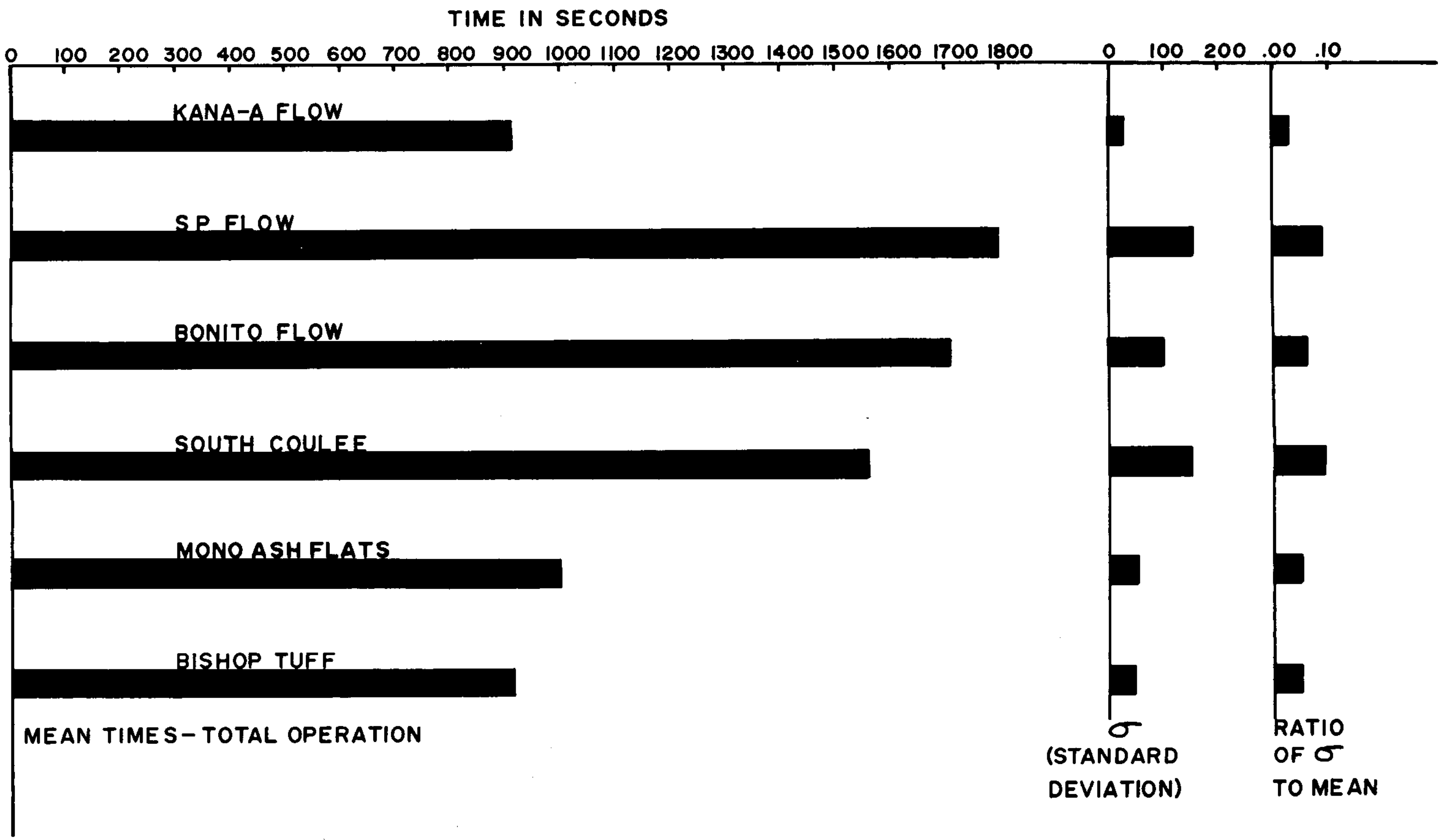


Figure 25.--Mean total operation times, standard deviations, and normalized standard deviations (ratio of standard deviations to mean) for Operator No. 2 at six sites. Operator No. 2 is the cable handler.

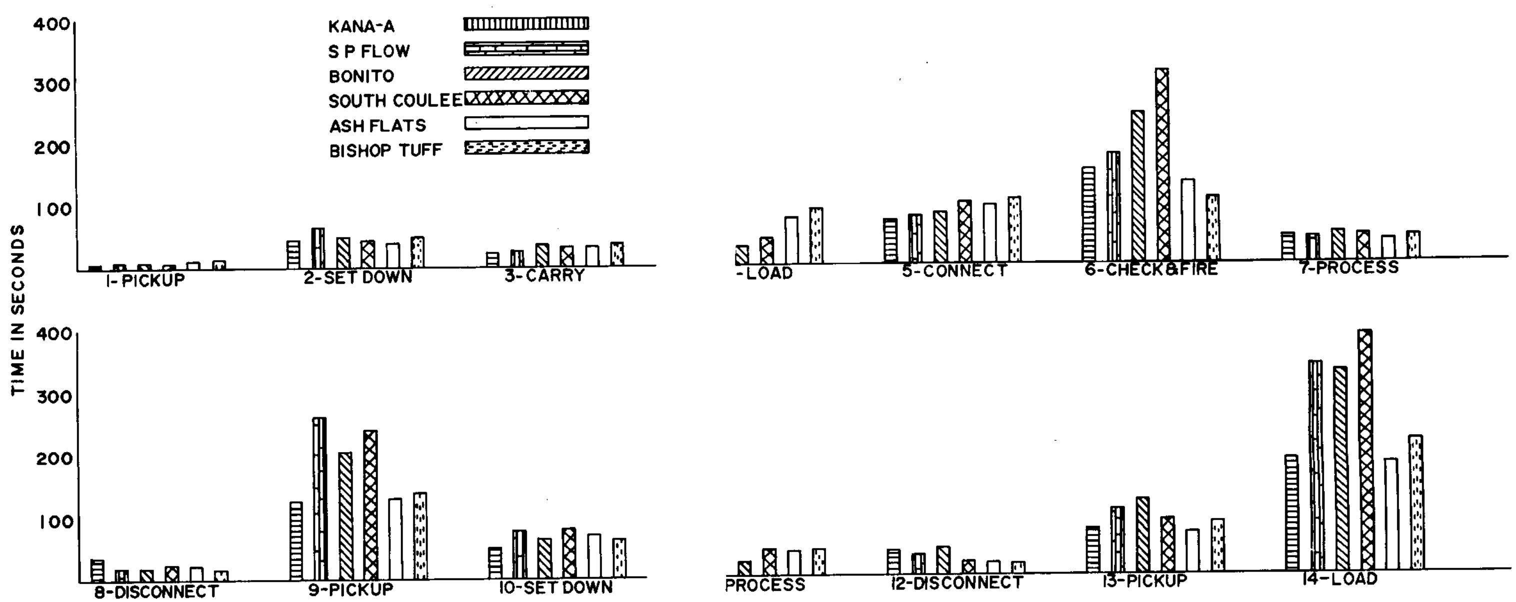


Figure 26.--Step-by-step mea :ration times for Operator No. 1 at six sites.

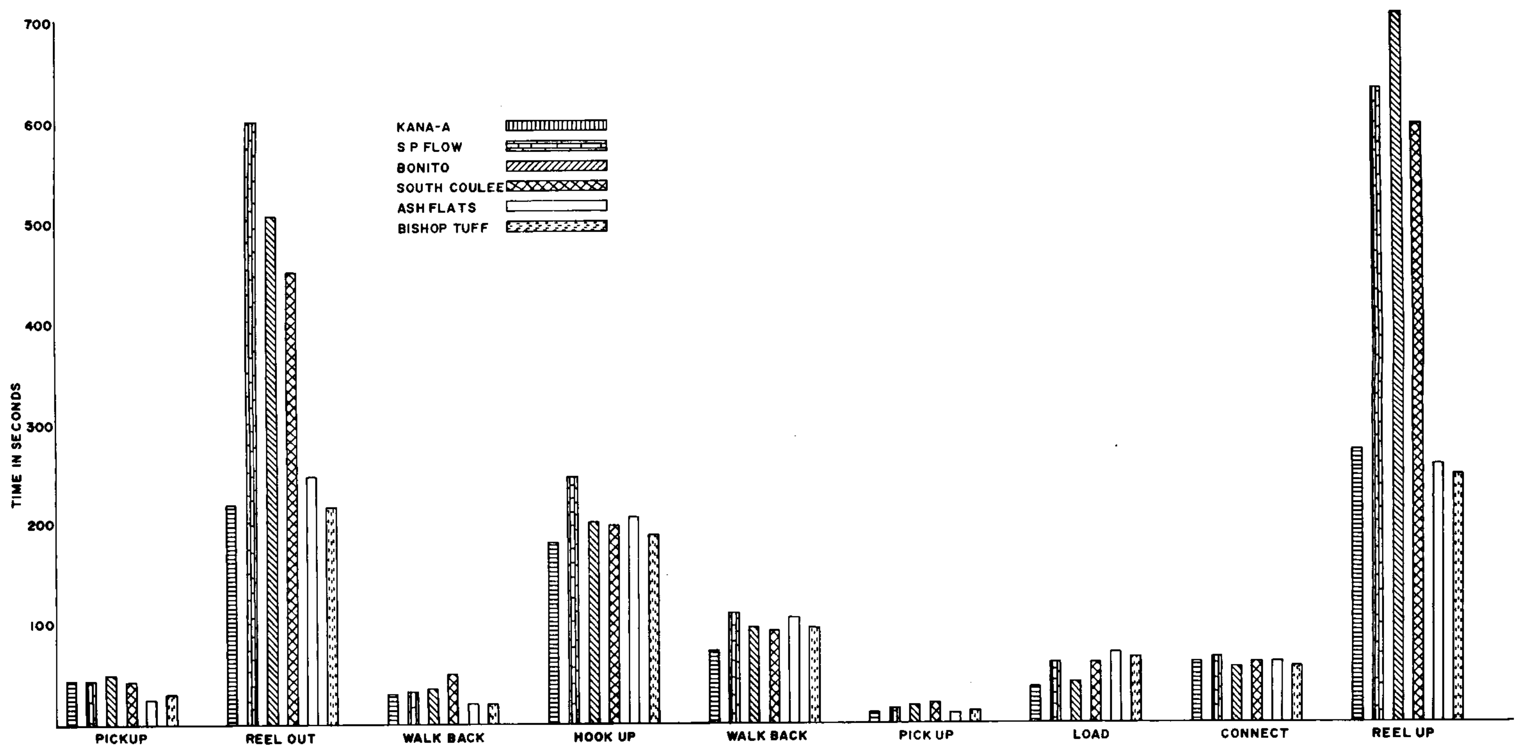


Figure 27.--Step-by-step mean operation times for Operator No. 2 at six sites.

and the difficult terranes. In the case of Operator No. 1, his check and fire and two pick ups are the steps whose times varied most widely. In the case of Operator No. 2, the reeling out and reeling up are the steps in which times varied most greatly.

Because walking time occupies such a large part of the total operation time for the seismograph, figure 28 has been constructed to show the percentage of the total time used in walking by Operator No. 2. For the easily traversable terranes the percentage of walking time ranged from 62 to 64 percent. For the more difficult terranes the percentage of total time involved in walking ranged from 76 to 79 percent.

Terrane Difficulty

The data presented in figures No. 24, 25, 26, 27 and 28 show that [illegible] for portable seismograph operations are directly related [illegible] correlation between terrane difficulty and times required for the different operators to conduct the different steps is not as clear as it is for the gravity meter operations. Unexplained is the reason why, in the difficultly traversable terranes, Operator No. 2 was able to complete his operations on South Coulee in a shorter time than on the Bonito or S. P. Flows, whereas Operator No. 1 required more time on the South Coulee than on the other two flows. There are similar unexplained anomalies which may be explained as more data on operational procedures are obtained. The anomalies in the individual times, however, are minor when they are compared to the times required for traverse.

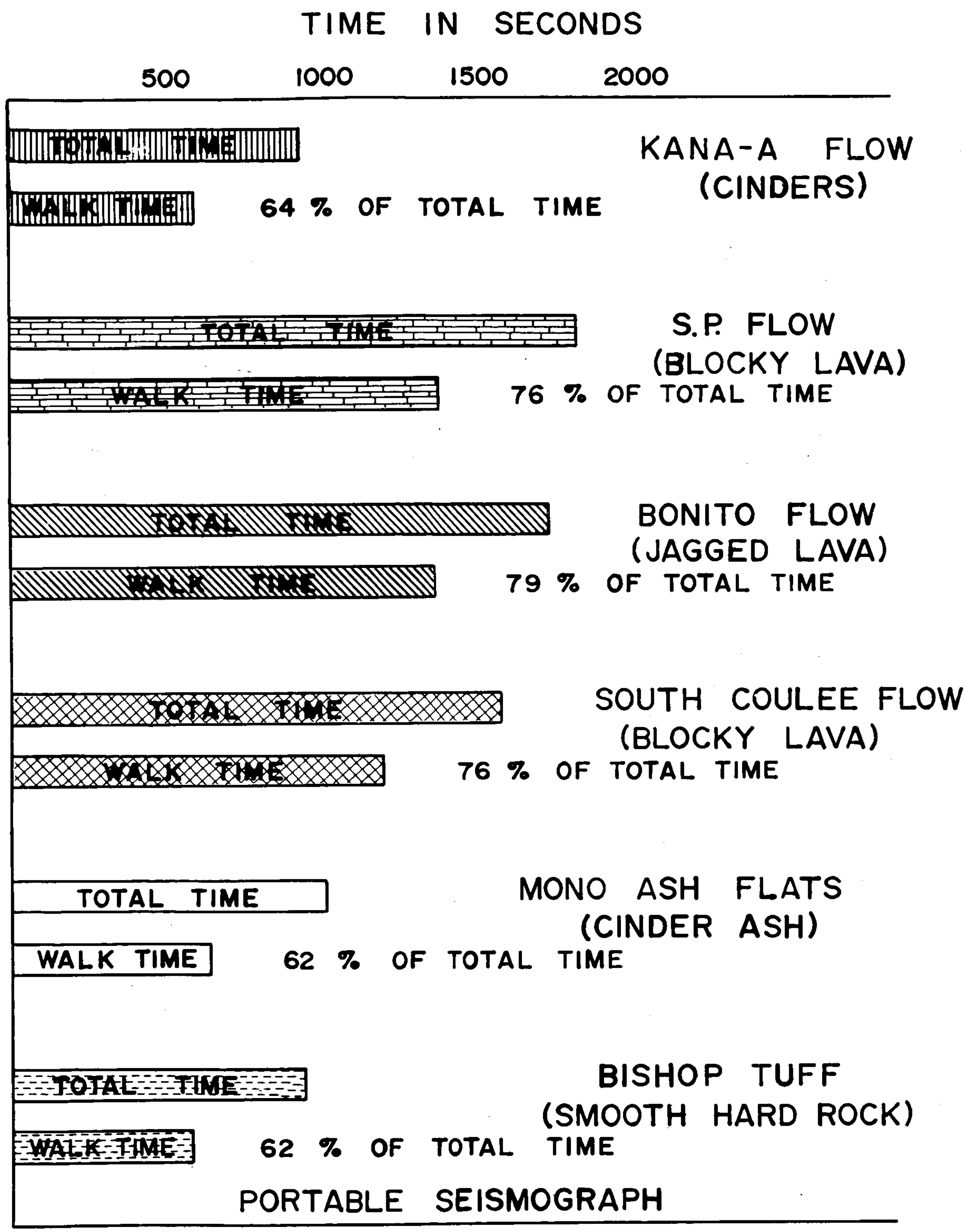


Figure 28.--Comparison of total times and walk time for Operator No. 2 at six sites.

This is one of the most important factors in the design of a lunar seismic experiment with the exception of possible hazards associated with the explosives used in the experiment.

Magnetometer Tests

Instrument

A proton precession magnetometer was used for the study. The instrument is carried on the operator's chest, and weighs 25 lbs. including batteries, sensing head, and connecting cable. This type of magnetometer was chosen because it reads total magnetic field rather than relative values of the magnetic field as is the case with many other magnetometers, because it is relatively light and compact, and

The magnetometer consists of a

and a sensing head. The electronic package contains: four silver-cadmium cells in series which combine for a nominal voltage of 5.6 volts, a 5.6 volt cartridge mercury battery used for the oscillator power supply, a polarizing relay, a programmer, a vibrating reed frequency meter, a range tuner switch, a function switch and a humidity indicator.

The sensing head contains a coil wire that encompasses a plastic bottle containing a proton-rich liquid. The sensing head, which can be attached to a staff or suspended from a bracket, is connected to the electronic package by a cable. The vibrating reed frequency meter contains 53 reeds spaced in 20 gamma steps providing a full scale meter range of 1040 gammas. The meter is calibrated in 100 gamma units up to 1000 gammas. The range selector has 12 positions which determine the magnetic field range in 1000 gamma steps. The range of the meter used was from 48,980 gammas to 61,020 gammas. Plug-in tuning units can increase this range from 19,000 to 101,000 gammas.

The measurement of the field intensity and fluctuations in the Earth's magnetic field is accomplished by the polarization and free precession of atomic nuclei in the sensing head. The frequency variations in the signal voltage induced by the precessing protons enables the precise measurement of the magnetic field variation.

Method of Operation

The operation of the magnetometer is a simple operation consisting of traveling a predetermined distance (in the case of these tests, 100 feet) between stations. The operation was timed by either an observer or the operator himself.

Field time and information tests were conducted at the three California test sites: South Coulee, Ash Flats and Bishop Tuff.

Times Required for Each Operation

The simple nature of the magnetometer operation does not require elaborate analysis of times required for each operation. The significant data are summarized in Table No. 9.

Scintillation Counter

A few tests of a scintillation counter conducted at the test sites yielded inconclusive data. The operation of the scintillation counter,

Table No. 9.--Total times, mean times, and standard deviation of mean times required for operation of the magnetometer across eleven station traverses on the South Coulee, Ash Flats, and the Bishop Tuff sites.

Site	Operator	Number of stations		Total time	Mean time	Standard deviations
South Coulee	1	11	Travel	694.2	63.1	21.0
			Read	470.8	42.8	13.8
			Total	1165.0	105.9	24.2
South Coulee	3	11	Travel	778.2	70.7	16.2
			Read	535.7	48.7	34.9
			Total	1313.9	119.4	37.5
South Coulee	3	11	Travel	711.0	64.6	20.7
			Read	497.9	45.3	23.5
			Total	1208.9	109.9	37.4
Ash Flats	1	11	Travel	316.4	28.7	2.2
			Read	377.1	34.2	16.4
			Total	693.5	63.0	16.3
Ash Flats	2	11	Travel	355.9	32.3	3.2
			Read	330.6	30.1	12.8
			Total	686.5	62.4	12.0
			Total	765.2	69.6	20.2
Bishop Tuff	1	11	Travel	351.1	31.9	2.3
			Read	476.8	43.3	11.8
			Total	827.9	75.3	13.1
Bishop Tuff	2	11	Travel	383.4	34.9	2.8
			Read	164.6	15.0	3.4
			Total	548.0	49.8	5.2
Bishop Tuff	2	11	Travel	394.9	31.8	5.0
			Read	362.9	33.0	11.0
			Total	757.8	68.9	11.0

however, is similar to that of the magnetometer and it is anticipated that the outcome of the time-motion data will be much the same as that obtained for the magnetometer. Known radioactive deposits occur in the Hopi Buttes area, Arizona, where operations with a scintillation counter will be conducted during the next report period.

LUNAR FIELD SURVEYING METHODS

(Yukio Yamamoto, Project Chief)

Introduction

The Lunar Field Surveying Methods project has been conducting time and information studies on standard surveying techniques and providing surveying support for Field Geological and Field Geophysical Investigations projects. During the first half of FY 1965, time and information studies have been completed on the use of the theodolite and the plane table and alidade. A documentary film (20 minutes) showing instrumentation and surveying techniques supplements this report. Control surveys were essentially completed for the Moses Rock project. Support operations for Field Geological and Field Geophysical Investigations test sites in the Hopi Buttes area began in January 1965.

Time and Information Studies

Time and information studies of standard surveying techniques and instrumentation were conducted on various terrains in the San Franciscan volcanic fields under normal field conditions. At the outset it was realized that standard surveying techniques and instrumentation would not be appropriate for use on the lunar surface. The studies were undertaken, however, to derive basic information necessary to develop and evaluate surveying operations applicable for lunar exploration.

The basic motions and surveying operations studied will serve as an aid to the design of mission operations. Standard surveying operations listed in Table 10 constitute basic operations essential to

Table 10.-Horizontal and vertical control operations [1/]

	aa Lava Flow		Cinder Slope		Level Ground	
	min.	sec.	min.	sec.	min.	sec.
Noninstrumental Operation						
1. Setup over nondesignated point	1	38	1	37	1	31
2. Setup over predesignated point with plumb bob	4	45	3	43	3	06
3. Setup over predesignated point with optical bob	4	38	3	32	2	47
4. Measurement of height of instrument (H.I.)	0	14	0	19	0	21
5. Search for 6 points	8	00	5	00	2	00
6. Take down	1	15	0	51	0	53
Instrumental Operations						
7. Turn 3 sets (direct and reverse angles), closed horizon	17	17	14	06	13	23
8. Turn 3 sets (direct and reverse angles), unclosed horizon	14	16	11	48	10	58
9. Turn 3 sets (direct and reverse angles), closed horizon, unstable setup	28	26	26	00	22	13
Vertical Angles						
10. Turn a direct angle to 1 point	0	46	0	38	0	41
11. Turn a direct and reverse angle to 1 point	1	11	1	08	0	58
12. Turn 2 sets (direct and reverse angles) to 6 points	15	06	13	36	13	04
Stellar Observations						
13. Third-order stellar observations on 2 random stars					21	26
14. Third-order Polaris observations					8	13
15. Turn 2 sets (direct and reverse) vertical angles to 6 points as in 12 with Askania theodolite					9	16

[1/] Wild T-2 theodolite used in all tests except in operation 15.

Table 11.-Average Times and Accuracies of Angular Measurements with Wild T-2 Theodolite

Test Site	Average Time		Average Deviation of Pointings
	Horizontal Angles 1/		
AA lava flow	20 min.	00 sec.	±03.3"
Cinder slope	17	18	±02.2"
Firm, level ground	15	31	±04.2"
	Vertical Angles 2/		
AA lava flow	15 min.	06 sec.	±02.0"
[illegible]	[illegible]	[illegible]	[illegible]
Firm, level ground	[illegible]	[illegible]	[illegible]

1/ 3 sets, direct and reverse, to 6 points.

2/ 2 sets, direct and reverse, to 6 points.

terrestrial horizontal and vertical control. This requires the measurement of azimuth and vertical angles to distant points with the Wild T-2 and the Askania theodolites.

Control Surveys with Wild T-2 Theodolite

The Wild T-2 theodolite, a standard instrument for horizontal and vertical control surveys by the Topographic Division of the Geological Survey, was used in all studies. Also used, but to a limited extent, was the Askania theodolite, a recently developed instrument having several desirable features, one a self-leveling index on the vertical circle. For experienced engineers, manipulation of the Wild T-2 and Askania theodolites for horizontal control are about equal. For this reason time and motion studies with the Askania were limited to observing vertical angles.

These field operations for control surveys employed two engineers of nearly equal ability and experience in this type of survey. Each operation was repeated on three distinct terrains: aa lava flow, loose cinder slope of 11° and firm, level ground. Six natural targets were chosen at random around the horizon at each location; all other conditions were considered constant.

Procedure.--Each operation required for both horizontal and vertical control work is listed in Table 10 with average time of three trials involved for each. The following list gives a brief description of each operation. Except where an Askania theodolite was used for reading vertical angles, all operations entailed the use of the Wild T-2 theodolite. The operations were:

1. Setup over nondesignated point. The operator sets the tripod over a desired location, mounts the theodolite on the tripod, levels, then readies the instrument for control operations. The station mark is then established by plumbing.
2. Setup over predesignated point with the plumb bob. The operator centers the tripod over the station mark with the aid of a plumb bob, then mounts the theodolite on the tripod and readies the instrument for control operations.
3. Setup over predesignated point with an optical plumb. This operation is similar to operation 2 except that the instrument is centered over the station mark with an op-

4. Measurement of height of instrument (H.I.). The height of instrument above the station mark is measured.
5. Measurement of a direct vertical angle to 1 point. This operation consists of pointing the telescope to a distant target, leveling the vertical circle, and reading the angle.
6. Measurement of a direct and reverse vertical angle to 1 point. In addition to operation 5, the telescope is "plunged" or reversed; then, in the inverted position, the telescope is pointed to the same target, the vertical circle is again leveled, and the angle read. This is the reverse angle, 180° around the vertical circle from the direct angle.

7. Measurement of 2 sets (direct and reverse) of vertical angles to 6 points. Operation 6 is repeated twice for each station.
8. Measurement of 3 sets (direct and reverse) of horizontal angles to 6 points, closed horizon. Starting with an initial station, the telescope is pointed successively to 5 other stations around the horizon in clockwise direction, then returned to the initial pointing. Horizontal angles are read at each pointing. The telescope is plunged and, again starting with the initial station, pointings are made to successive stations around the horizon counterclockwise and back to the initial point. When 1 set is thus completed, the procedure is repeated twice, changing the horizontal index at the beginning of each set.
9. Measurement of 3 sets (direct and reverse) of horizontal angles to 6 points, unclosed horizon. Same procedure as operation 8 except that after pointing to the sixth station, the telescope is reversed and pointings are made counter-clockwise back to initial station.
10. Measurement of 3 sets (direct and reverse) of horizontal angles to 6 points, closed horizon, unstable setup. In this operation, direct and reverse observations are made between 2 consecutive stations at a time around the horizon.
11. Third-order stellar observation on 2 random stars, night observation. Three sets (direct and reverse) of horizontal and vertical angle pointings are made to 2 randomly chosen

stars, noting time of pointing; the pointings are referenced to a terrestrial station.

12. Third-order Polaris observation. With the horizontal circle referenced to a terrestrial station and telescope pointed to Polaris, time of pointing and horizontal angle are recorded for 3 direct and 3 reverse pointings.

13. Search for 6 points. This operation takes place before any measurement begins. In selecting 6 distant natural targets consideration must be given to distribution around the horizon, definition and recoverability both from the occupied station and the next station to be occupied.

14. Take down. The instrument is dismantled and equipment is prepared for transportation to next point.

Plane Table

A second series of studies was conducted in the Bonito Flow of the standard operations of plane table and alidade surveying under normal field conditions.

An alidade is a versatile instrument. For control purposes it is primarily used for vertical control work. The instrument also is used in certain situations for mapping topography and geology, for leveling, and for establishing horizontal and vertical control by graphic triangulation and by plane table traverses.

The instrument and equipment used in the studies are standard with the Topographic Division of the U. S. Geological Survey. The instrument used was the Keuffel and Esser Self-Indexing alidade, which has a prism-pendulum system that automatically sets the index on the vertical circle. A 13.2 ft. foot-meter stadia rod, an 18" x 24" plane table board and Johnson tripod constituted the equipment used on the tests.

Procedure.--The following operations were conducted on three types of terrain: basaltic aa lava flow, cinder slope, and firm level ground. The procedures and times are listed in Table 12.

1. Setup and orientation. This involves mounting the plane table on the tripod, setting tripod over station mark, removing the alidade from case, then leveling with the aid of a bullseye level mounted on the blade of the alidade, and lastly orienting the board with the magnetic compass.
2. Setup during stadia traverse. This operation begins with plane table board mounted on tripod and alidade in hand.
3. Level shot reading. With plane table board leveled, a level reading made on distant rod and the observed reading recorded.
4. Beaman Arc reading. With plane table board leveled, the stadia distance read on the rod intercept, an even Beaman (division of arc) set, rod setting read, and the three observations recorded.
5. Location by intersection. To determine a position graphically with plane table and alidade, the new point must be intersected from at least 3 established horizontal stations. Because the operations are identical at all stations, the procedure at only one station was timed. This operation

Table 12.--Plane Table and Alidade Operations

Experienced Operator	Inst. K & E Self-Indexing					
	Terrain					
Operation	aa Lava		Sloping Cinder		Firm Flat	
	min.	sec.	min.	sec.	min.	sec.
1. Setup and orientation of board	2	20	1	57	1	37
2. Setup during stadia traverse	0	32	0	35	0	33
3. Level shot reading	0	36	0	30	0	27
4. Beaman arc reading	0	36	0	40	0	40
5. Location by intersection	2	10	1	44	1	35
6. Location by resection	2	10	2	00	1	45
[illegible]	[illegible]	[illegible]	4	30	5	15
8. 473 Ft. stadia traverse-- vertical control	14	28	4	43	4	13
9. 473 Ft. stadia traverse--horizontal and vertical control	16	34	6	33	6	00
10. Tear down	1	10	1	11	1	09

consists of setting the plane table directly over the station, orienting, then sighting on new point with the blade of the alidade passing through the occupied point (the three stations occupied to intersect the new point have been plotted on the board previous to field work) and drawing a ray through the vicinity of the new point. Travel between stations was a variable not considered here.

6. Location by resection. The first part of the operation is identical to Operation 5 and is not described here. The plane table is set over the new point, oriented by back-sighting along the pencil ray drawn at previous station occupied, and resected from orientation on the remaining distant stations. The pencil rays should intersect at one point, but commonly form a small triangle.

7. 3-point location. This operation beginning with plane table set over new station whose position is to be determined graphically. At least 3 previously established stations must be visible and preferably a fourth as a check. The board is oriented first by magnetic or sun compass, then resected from three stations. This generally produces a triangle of error. The procedure used here is a method of direct trial, until repeated reorientation and resection results in a point intersection.

8. Short traverse-vertical control. During this sequence of operations the instrument man and rodman move from a bench

mark to a turning point. The instrument man makes a backsight and a foresight from an advantageous instrument setup between the bench mark and the turning point.

9. Short traverse-horizontal and vertical control. This operation is identical to 8, with the added task of carrying horizontal position graphically.

10. Take down. The alidade is replaced in the case, plane table board removed from tripod and tripod folded.

Results and Discussion

Wild T-2 Theodolite

The results of the studies on the standard horizontal and vertical

in Tables 10 and 11.

Table 10 presents the time required to carry out various operations at any one station to extend horizontal and vertical control. The type of terrain was the primary factor affecting the timing of each operation. Where an operation was accomplished from a single standing position, such as measurement of instrument height and one vertical angle, there was no noticeable difference in elapsed time on the three terrains. However, where movement about the instrument setup was required during an operation, there was a significant change in the elapsed time (note operations 2, 3, 7, 12; Table10). The aa lava flow presented difficult footing, the cinder slope presented much easier footing but care had to be exercised not to step too closely to the

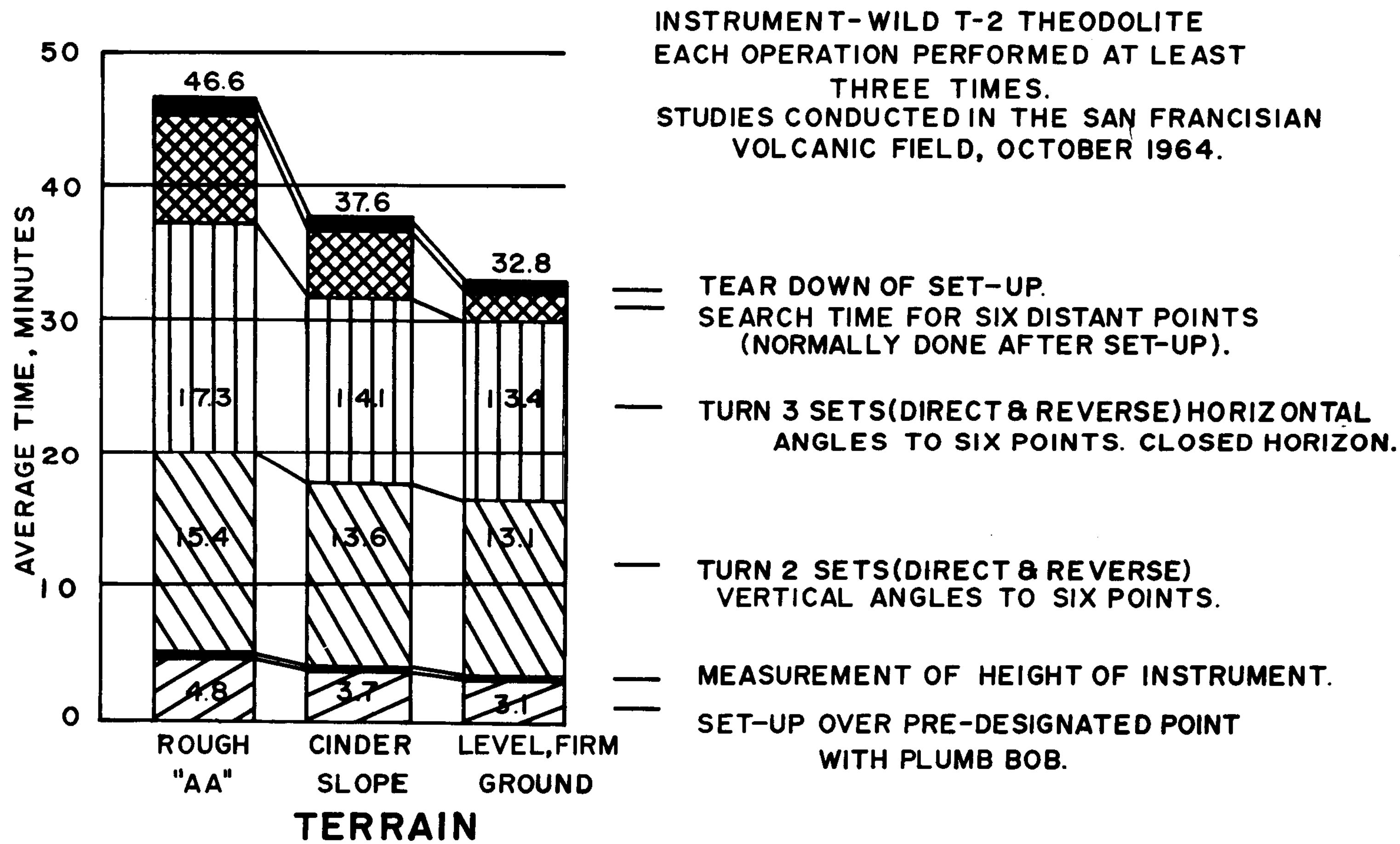


Figure 29.--Time and motion data for horizontal and vertical control surveying operations

tripod legs; and the firm, level ground allowed the operator to move freely about the instrument setup.

Other than terrain, all other field conditions were largely constant for all tests. The weather varied somewhat, from clear to cloudy, but this did not hinder observations significantly. The selection of natural targets at each site was also considered constant. Targets, such as a point of rock or the top of a twig were randomly chosen around the horizon. Each operation was conducted in as nearly identical a manner as possible at each of the three sites.

Not all operations listed in Table 10 were carried out at each station. In Figure 29 may be found operations normally carried out at a station to obtain data for horizontal and vertical control (2, 4, 5, 6, 7 and 12 in Table 10). This standard control survey required

slope and 33 minutes on the firm, level ground.

Table 11 presents a summary of the relative accuracy obtained from each trial for horizontal control operations conducted at the three sites. Table 11 also shows a summary of the relative accuracy obtained from each vertical control operation. Throughout the tests the accuracy remained nearly constant and well within third-order requirements (1 part in 5000), regardless of terrain. A review of the field notes indicated that any one raw horizontal angle reading could be acceptable for near-third order accuracy.

Plane Table and Alidade

Plane table and alidade surveying techniques, if applied to surveillance systems on LEM or on a mobile laboratory, are applicable to exploration of the lunar surface. Elapsed times shown in Table 12 are for various operations on three types of terrain. The simplicity of the alidade is indicated by the fairly short time for each operation. Here again, trafficability of the terrain was the primary factor affecting completion time (see operations 8 and 9, Table 12).

A distinct advantage of plane table and alidade techniques for mapping topography or geology is that a map can be compiled as the work progresses. The geologist can develop his interpretation of the geology as the data are plotted. The LEM surveillance system would act as an alidade, the progress of and data obtained from the surface astronaut could be compiled on an X-Y plotter (the plane table) on earth in near-real time.

Mobile Laboratory Studies

Surveying techniques for carrying control during roving vehicle traverse began in January 1965. Modification of a 4-wheel drive vehicle for testing and developing surveying operations was completed. A ranging laser, which will be mounted on the vehicle together with a theodolite, was obtained on loan. Testing is scheduled to begin in January 1965.

Support Activities

Film Documentation

About 5000 feet of 16 mm. black and white film showing operation of 2 theodolites, the plane table, and alidade is available for analysis. A short film has been compiled showing types of surveying operations documented for time and motion analysis.

Control Projects

As a support activity, the surveying project has been obtaining control for the compilation of large scale topographic base maps. Horizontal and vertical control was begun at Moses Rock, Utah, in October 1964. The horizontal control and approximately 80% of the supplemental vertical control have been completed.

Summary

Time and motion studies on the surveying techniques and instrumentation under shirt-sleeve conditions have been completed. The data show that single pointing reading operations require on the order of one minute. Analysis of the horizontal and vertical control data shows that single angular measurements are feasible with a 1-second reading theodolite to obtain near-third order accuracies. Such accuracies may be required for certain lunar exploration activities.

Plane table and alidade surveying techniques provide a simple and direct mapping capability for the geologist. Properly modified and automated they would permit the extraction and compilation of field data at an Earth-based facility as the field investigation progresses.

Photogrammetry

(J. D. Alderman and J. L. Derick)

Introduction

The MLEI program contains, as a support for geologic mapping, a continuing investigation of photogrammetric systems and techniques. During the first half of fiscal 1965 the main system investigated was an electromechanical imaging system adaptable to photogrammetric plotting. In addition the usefulness of stationary camera positions on the LEM was considered.

The geologic applications of photogrammetric techniques are numerous. Some of these applications are:

1. Quantitative scaling of geologic features such as contacts, small structures, and textures.
2. Portraying areal and size distribution and nature of surface features such as craters or ejecta blocks.
3. Directly showing relationships of geologic and topographic features for geomorphic studies.
4. Allowing observed features to be related to planimetric base, thus saving considerable time in geologic mapping where contacts or structures are exposed. This could be coupled with adequate sampling to produce a standard map, or used to construct interpretive geologic maps from areas beyond the range of astronaut mobility.
5. Remotely describing and measuring horizontally layered material exposed in bluffs, crater walls and cliffs,

with or without later sampling. This technique has been field tested with favorable results (see Appendix D).

6. Relating geologic and topographic features seen on the surface to the orbiter photographs. This would then allow the extrapolation of these features to other areas that appear similar on the orbiter photographs.
7. Locating stations by photographing the astronaut at the station.

The above and other applications of photogrammetry will be investigated in further tests.

Data reduction complexities are defined by state-of-the-art photogrammetric instrumentation. A plotter presently exists that is capable [illegible] types of imagery which might be obtained in a relatively [illegible]

The near-real time mapping capability will allow the plotting of a roving astronaut's traverses and small areas of study before completion of the mission. In this manner it will be possible for Earth-based scientists to correlate and evaluate the mission before the astronaut reenters the LEM, thereby permitting evaluation of the mission and requests for additional information.

Electromechanical Camera Imagery from the LEM and the Lunar Surface

To obtain stereo terrestrial photography with measurable accuracies that are comparable to vertical stereophotography, requires such constraints to be placed upon any imaging system, that only a limited number of systems may be employed. The present study indicates that an electromechanical system will satisfy the requirements.

The electromechanical facsimile camera, developed by Aeronutronics, fulfills one particular mission requirement; to obtain about the LEM full field (360°) stereophotography of stable geometry, high resolution (0.1° or less) and X parallax of sufficient quantity to be measured at 80 meters with a 0.001 percent accuracy. This system has the added advantage that the requirement can be accomplished automatically with the camera mounted on top of the LEM.

The facsimile camera provides an image by scanning a field through an electromechanical motion. This differs from the cathode ray tube, where scanning is performed with an electron beam. The basic conception of fixed focus optics in the most elemental form with a solid state detector results in a very compact, light-weight, small-volume package that appears very applicable to Apollo photographic requirements.

Consideration of some attainable parameters of the camera indicates the advantages of an electromechanical scanning system:

1. Vertical field: 90°, +30 and -60°.
2. Horizontal field: 360° in a stereo-mode.
3. Angular resolution: 0.05°.
4. Time lower limit (present configuration): 5 minutes.
5. Band width: indefinite.
6. Image point stability: 0.03 to 0.01°.
7. Luminance threshold: 5 to 500 foot lamberts with capability to respond to 2500 foot lamberts.

8. Dynamic range: 100:1

9. Transmission data: analog.

10. Environmental: thermally controllable with electrically neutral viewing window.

11. Spectral response: depending on detector, a good part of visual and infrared.

12. Weight: camera, electronics, and drive motors combined, less than 12 pounds.

In order for a photogrammetric system to function efficiently, there must be geometric compatibility between the imaging device, reproduction equipment, and plotting instrument. Available in a production form is an analytical stereoplotter that can handle a wide range of parameters and give first order results.

1. Format size may range up to 9.5 x 9.5 inches.
2. Film transparencies on glass plate diapositives may be used in plotter.
3. Focal lengths may vary from 1" to 12".
4. Accommodates a wide range of angular field.
5. Angular deviations of $\pm$ 5 degrees can be corrected.
6. Coordinate reading is 5 microns direct at mode scale.
7. Model orientation is performed either manually, analytically, or a combination with minimal orientation time.
8. Automatic profiling.
9. Known film distortions, curvatures, and image motion corrections are fed directly into operating mode.

The plotting of electromechanical imagery has less attendant problems than that of vidicon imagery.

The reproduction (play back) of electromechanical data is the weakest link in the photogrammetric chain. Some research and development is required to produce a suitable play-back system. Technical studies by Aeronutronics demonstrate that the amount of research and development necessary to upgrade the play-back system is small.

The functional requirements for a play-back system are:

1. Must have stable base, with near-real time reproduction.
2. Must have resolution within the limits of 0.01° to 0.03°.
3. Must correct known electronic or optical aberrations at time of play back.
4. Must store and reproduce data almost simultaneously.
5. Must have a dynamic range comparable to that of the electromechanical imaging system.

Techniques.--Three possible techniques can be used to obtain the desired panorama using a single camera. Constraints of weight, power, and band width accommodation prohibit the employment of a 2 camera system on the early Apollo missions.

Technique number 1 is in all aspects the best of the three in terms of efficiency, automation, and time. The other techniques are considered for use in emergency modes.

Technique Number 1.--Should a periscope be a part of the LEM design, the placement of an automated electromechanical scan system would logically fall into a share category with the alloted opening.

The electromechanical scan system must be mechanically and environmentally independent of the periscope.

If the periscope is not included on LEM, the electromechanical system would greatly benefit in terms of increased weight allowance that could be used to insure maximum efficiency.

Without benefit of specific constraints, the three modes of operation of the electromechanical system are briefly stated. One or two minutes after impact a servo motor would drive the telescoping tube containing the camera into its lower position. The time lapse is to allow for dampening of vibration. Automatic scanning operation commences and continues until the required scan is complete. The servo motor then drives the telescoping tube to its second position, a point where an effective two meter vertical base separation between camera

spected at Manned Space Information Center for completeness. Scientists and engineers will start immediately to evaluate the imagery and format layout using a photogrammetric plotting instrument. Upon completion of the lunar surface mission, if no additional panorama or portions thereof are required, the facsimile system will be automatically ejected from LEM.

Technique Number 2.--This technique achieves the same results as technique number 1. The basic difference is that the facsimile camera would be mounted manually to brackets on a tripod on top of the LEM by an astronaut for its lower position. Raising the camera to its upper position would be accomplished manually or by a servo motor.

The main drawback to this technique is that the astronaut must spend time performing the operation. It will require the astronaut to leave the LEM with a device (tripod) to hold the facsimile camera to an oriented stable mode, then reenter the air lock for the camera, and finally make the required power connections. Some weight or space might be saved by employment of this technique.

Technique Number 3.--This technique entails the placement of the facsimile camera on the lunar surface in locations about the LEM, which would be limited by the length of the umbilical power cable. The evaluation of this technique is outlined below; one based upon a vertical stereobase, the second on a horizontal stereobase separation.

Vertical stereobase pairs would be taken from two positions on opposite sides of the LEM. The operation would involve setting up a tripod on the surface, leveling it, setting the camera at its low position and allowing it to record the panorama, and then setting the camera at its upper position to record a second panorama. This is similar to technique number 2, except that the equipment would have to be carried out onto the lunar surface and the operation performed separately at each station. A second leveling procedure would probably be necessary at the upper position, and the problem of stability and orientation may make it impractical to obtain a base separation of greater than one meter.

This technique with a vertical base would obtain good stereo coverage of the area about the base of LEM.

A horizontal base separation involves considerably more problems. Four positions would be necessary around the LEM. If the 75 foot cable connecting the camera to the LEM were used to its limit the camera positions would be about 75 feet and 57 feet from LEM along one axis and 67 feet and 67 feet along the perpendicular axis. The base separation between adjacent positions would be about 94 feet on one side of the LEM and 110 feet on the other side. The separation achieved along the axes would be about 140 and 148 feet respectively.

Base separations of this magnitude would give good control out to about 4,000 feet if nothing obstructs the view; however, much of the near field would be sacrificed. There would be no usable stereo coverage within the area encircled by the camera positions due to too great a parallax and scale change. Much of this area could be covered

to positions adjacent to LEM, although the total field would then be reduced considerably.

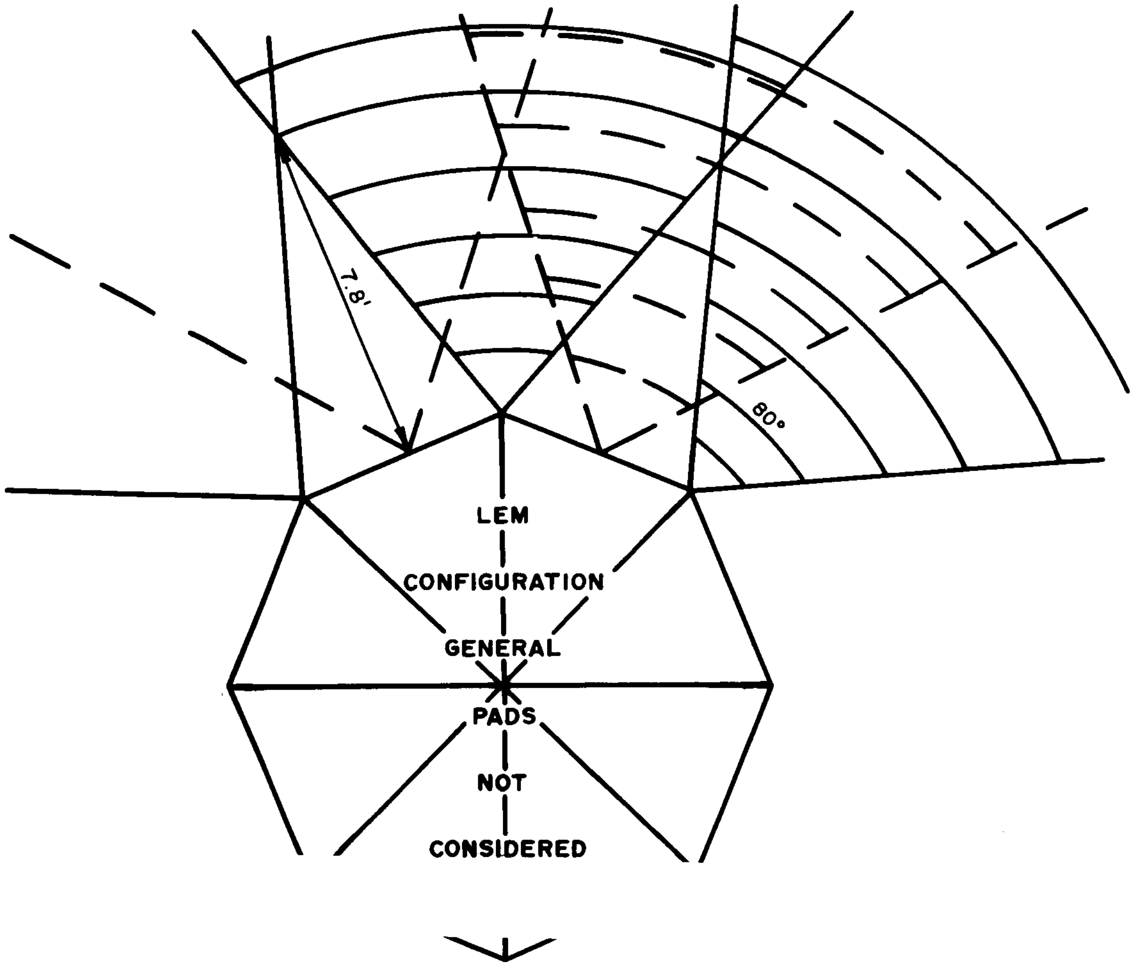
A horizontal base electromechanical technique would require ground control for the base lines and would introduce a great many problems in plotting that are not present when a vertical base is used.

Both of the variations of this technique have an advantage in that they would not be effected by any vibrations of the LEM and would not need a long telescoping mast. However, the view from the ground level would not be as good as that from the top of the LEM and, most serious of all, a considerable amount of the astronauts' time would be used performing the tasks necessary for the operation.

Photography from "Clips" or other Devices Mounted Outside the Descent Stage of LEM

Stationary camera clips on the exterior of the LEM could be used to obtain film stereophotographs of the area surrounding the LEM. A stereocamera would be moved from one clip to the next around the LEM and since the position and orientation of each clip would be known, photogrammetric analysis could be accomplished with the resulting stereophotographic coverage. To obtain horizontal base stereo coverage of the entire area around the LEM, 16 camera positions would be required. This could be accomplished, either by placing a clip on each corner and in the center of each flat surface of the spacecraft, with the optical axis of the camera perpendicular to the vertical axis of the spacecraft (see figure 30), or by mounting a clip on each corner that would permit the camera to be placed in two positions. These two positions would point the camera in opposite directions and the optical axis of each would be 40° from the flat surface of the side of LEM (see figure 31). The obstruction of view by the legs of the descent stage is partly overcome by the use of a stereo camera and may be ignored for the rest of the field of view. Positioning of the cameras on the legs of the descent stage to avoid any obstruction of view would increase the number of camera positions to twenty in order to fill in gaps in the near field.

Because of the heavy demands on astronaut time required when the camera is moved from position to position, the camera clip system is being considered as a backup system to be used if other means of

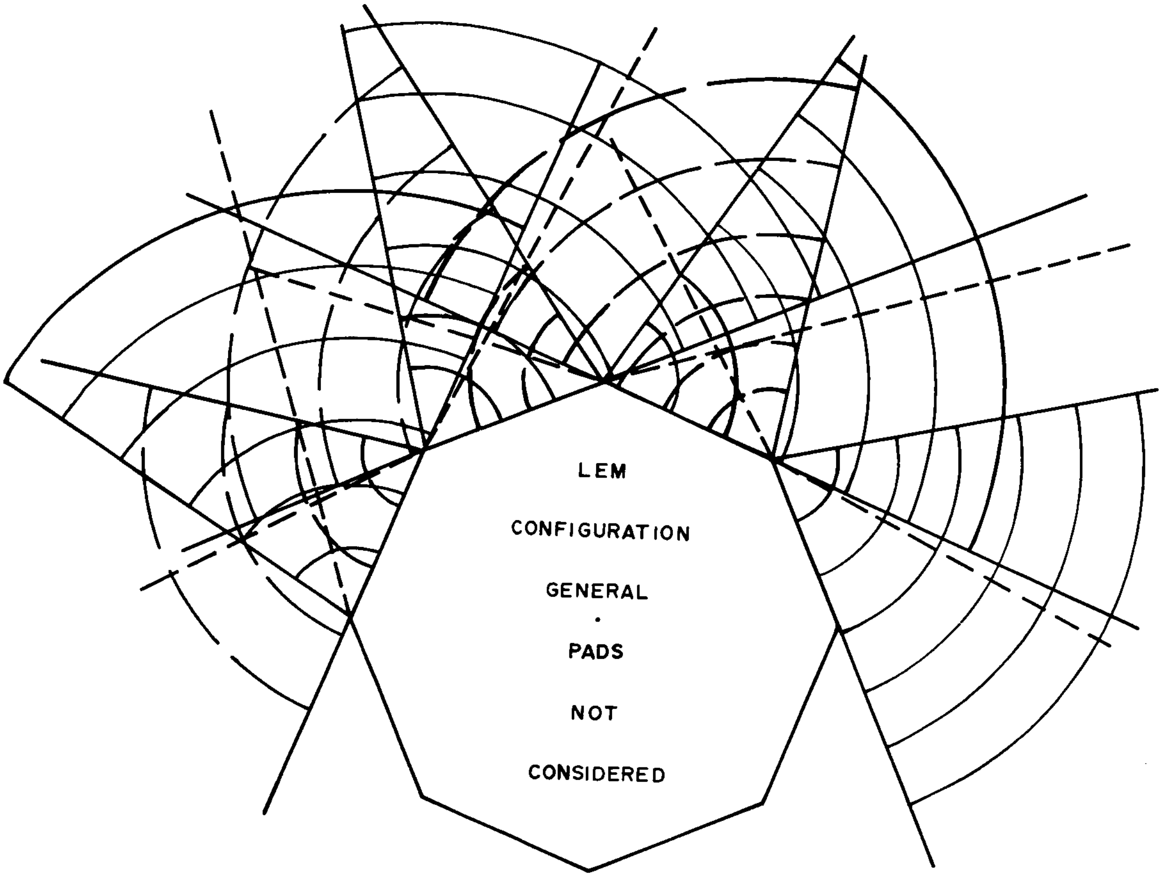


Photography from "Clips" on LEM

16 STATIONS

80° FIELD OF VIEW

Figure 30.--Overlap of fields of view for cameras mounted on single position camera clips at the corners and mid-face areas of the LEM.



PHOTOGRAPHY FROM "CLIPS" ON LEM

8 STATIONS
2 VIEWS FROM EACH STATION
80° FIELD OF VIEW

Figure 31.--Overlap of fields of view for cameras mounted on two-position camera clips at each corner of the LEM.

obtaining fixed base stereophotographic coverage of the landing area is not available. The primary advantage of the camera clip system is its very low weight.

ELECTRONICS INVESTIGATIONS FOR LUNAR FIELD SYSTEMS

(R. H. Barnett, Project Chief)

Introduction

The objective of the Electronics Investigations for Lunar Field Systems project during the first half of fiscal year 1965 was to investigate electronic systems for the acquisition of geological, geophysical, and surveying data in field operations, and systems to transmit, receive and record these data. In completion of this objective, systems suitable for the conduct of mission operations and testing were established. These include a microwave relay system and its associated test equipment; a LEM mock-up mounted surveillance television system; and field and base voice radio system.

Laboratory Investigations

Command, Data Reception and Analysis (CDRA) Facility Systems

Command, Data Reception and Analysis (CDRA) facility study has progressed to the point where major equipment can be specified and layout and inter-connection diagrams made (see figures 32 and 33). Equipment now installed and tested in operation includes an RCA model TVM-1C television microwave receiver, with sound channel; a KinTel model GRM-17 television monitor; and a General Electric remote control unit for the VHF radio system.

The microwave system has a 7 megacycle bandwidth capability and the sound channel has an audio frequency bandwidth of 50-15000 cps. The television monitor has a 10 megacycle video bandwidth to ensure

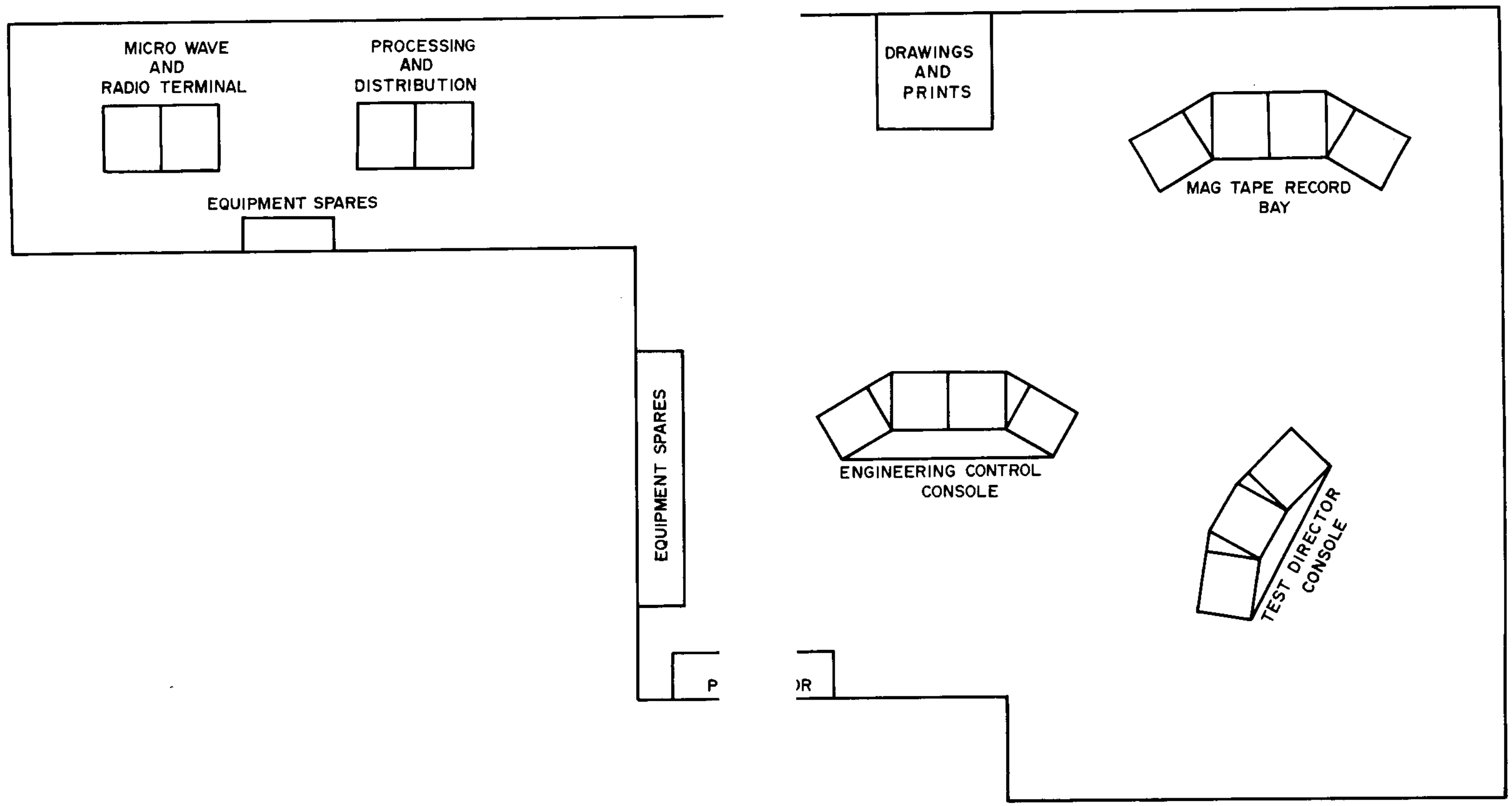


Figure 32.--Floor plan for the nand, Data Reception and Analysis facility.

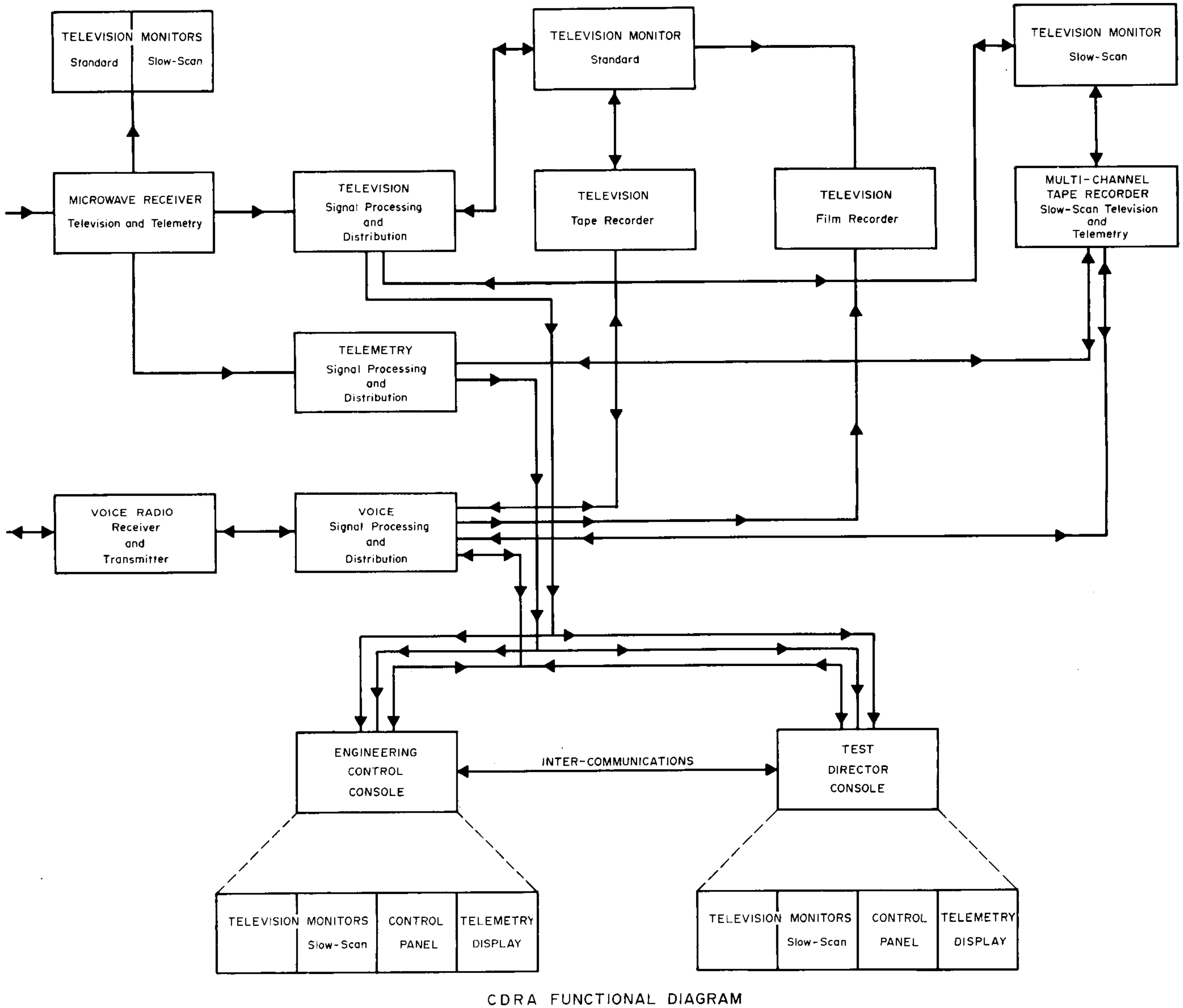


Figure 33.--Equipment interconnections and functional diagram for the Command, Data Reception and Analysis system.

acceptance of the de-modulated television and synchronizing signals from the microwave receiver.

The VHF voice radio transmitter (100 watts output power) and receiver (leased from General Communications, Inc., Flagstaff, Arizona) are installed in lessor owned facilities on Mt. Elden, near Flagstaff. The remote control unit is connected to the transmitter and receiver by Mountain States Telephone and Telegraph Co. lines on a monthly rental basis. The system operates on 164.525 mc, assigned by the Interdepartmental Radio Allocation Committee with a 16 kilocycle bandwidth, in accordance with U. S. Department of the Interior regulations. The antenna system, common to transmitter and receiver is a quarter-wave vertical radiator, with ground plane, affording 360° horizontal coverage, limited only by topography, at a maximum range of approximately

A Sony Corporation model PV-100 portable television magnetic tape recorder has been received and is undergoing laboratory testing. The recorder has two-sound-track capability in addition to accepting standard television signals. It will be rack-mounted in the CDRA, base or field, and provide primary recording of the surface astronaut's television camera signals or the LEM mock-up surveillance television signals, on a time shared basis. Twenty reels of tape were procured to provide twenty hours recording time.

A portable television film recorder, H. W. Palmer model VFR-2S was ordered, with delivery scheduled for January 1965. This will provide full-frame recording of standard television signals, as well as sound track, on 16 mm movie film. This will yield film for photogrammetric analysis, operations analysis, and general documentation, and will serve as back-up for the tape recorder. Additionally, primary television records on magnetic tape can be selectively filmed by the film recorder in post-mission operations documentary film preparation. The recorder will be installed in the base or field CDRA, according to operations requirements.

Specifications were written and bids received and evaluated for the procurement of a seven channel magnetic tape recorder. The contract is expected to be awarded in January 1965 with a delivery time of 120 days. The recorder will have the capability of recording a bandwidth of DC to 500 KC on two channels, and 400 cps to 1.5 mc on the other five channels. The machine will be used as the primary recording system for narrow-band television from the lunar surveying staff or surveillance camera, and for time-correlated telemetered staff, periscope data, and voice control.

Relay Systems

Relay system investigations, insofar as frequency assignment and site location are concerned, were defined by topography and regulations. Topographically, Mt. Elden, near Flagstaff, Arizona, is the best location for the near field operations relay. In the interest of economy, permission was obtained to use existing antenna towers and buildings from their owners, and the U. S. Forest Service, Department of the Interior. Forest Service permission was required because Mt. Elden is part of the Coconino National Forest.

Early implemented field operations can use "hard-line" connections between the astronaut television camera and the LEM mock-up. Accordingly, cabling design is in progress, to include all links between astronaut, LEM mock-up, and the radio-microwave field (LEM relay) terminal. The radio-microwave field terminal will be housed in a van, and a nearby portable generator system will provide power to the van and the LEM mock-up. The field terminal will consist of a VHF voice transceiver (25 watts transmitter power) and microwave transmitter. It will include equipment to process data from the astronaut's surveying staff and the LEM mock-up periscope for transmission by the microwave link. Additionally, circuitry will be included to permit commands via the VHF radio link to select either the LEM mock-up surveillance camera signal, or the astronaut's staff camera signal, for transmission by the micro-

be carried in the van.

Lunar Excursion Module (LEM) Mock-up Systems

LEM mock-up systems investigations include: surveillance television; communications between astronaut, LEM mock-up and CDRA; periscope data acquisition; and recording of staff and periscope data. State-of-the-art and availability investigations required visits to various NASA facilities and contractors, to determine applicability within probable technical constraints.

In view of development time and costs for a special system required, it was decided to use readily available components wherever possible.

A KinTel Model 2020 (modified) television camera and monitor were procured for surveillance of the surface astronaut. A small (5") monitor for the LEM mock-up astronaut will allow television observation of the surface astronaut. The system, operating at commercial rates, will be wired to the LEM relay van for transmission to the CDRA, via the microwave link. Astronaut to LEM mock-up to CDRA communications will be handled by cabling to the LEM relay and VHF radio link. (Note: Early shirt-sleeve operations communications will be accomplished by using portable transceivers, with no relay to CDRA.) Investigations of periscope elevation, azimuth, and range data read-out methods has progressed to the point where design can begin. Read-outs will be from position transducers mechanically coupled to the periscope controls. This information will be hard-lined to the LEM relay for FM/FM transmission to CDRA via the microwave sound channel, on command of the periscope operator.

Magnetic tape recording of voice and data will be accomplished by a suitable recorder in the LEM mock-up or LEM relay. There are several manufacturers of this type of equipment and an approximate model will be purchased when required.

At Westinghouse Corporation, Aerospace Division, Baltimore, Maryland, various television systems were observed and discussed. A molecular circuitry television camera, with a 1" diameter vidicon camera tube was shown as an example of high density, small volume packaging capability. The Secondary Electron Conduction (SEC) vidicon camera tube was described. Westinghouse plans to reduce the size of the tube, and in combination with molecular circuitry, produce the Apollo PAO camera. A thermal study mock-up of the PAO camera was shown.

Radio Corporation of America, Astro-Electronics Division, Princeton, New Jersey, showed various space-project imaging systems with possible application to lunar exploration. Nimbus weather satellite cameras were described. These use an image storage technique in a vidicon camera tube, for single frame storage and command read-out. Also seen was a space-flight qualified image orthicon camera. RCA's television simulator facility was demonstrated. This is a system to simulate television pictures at various line and frame rates, to study image qualities as a function of these variables.

Laser ranging systems were discussed for possible application to a walking astronaut tracking system (from the LEM mock-up). Westing-

could be combined with ranging circuitry and servo systems for auto-tracking.

Vehicular mission systems.--A portable laser ranging system was demonstrated at Ft. Monmouth, New Jersey. Arrangements were previously made through NASA headquarters to use the instrument in field studies for application to lunar field surveying. Possibilities of improving the system to accuracies required for surveying were discussed. Surveyors of MLEI will use the instrument in field studies, and with the assistance of the electronics investigations project, will generate accurate requirement specifications.

The LEM exploration systems discussed above and the laser ranging system for surveying are applicable to extended vehicular mission operations. In this case, all relaying functions will be housed in the mission vehicle. Additionally, all astronaut staff data and communications will have to be transmitted via R.F. link to the mission vehicle. The housing of transmitter packages within the surveying staff, for video, voice radio, and telemetry is under consideration. The limiting constraint may prove to be the volume of power source versus mission time.

Microwave relaying from a mission vehicle in motion will require an automatic pointing system. As this requirement becomes firm, investigations into methods of achieving this will be conducted.

Astronaut Systems

Astronaut systems will include communications, television, and staff data sensors. Communications will be via cable between astronaut and LEM mock-up and between LEM mock-up and the LEM relay van. Here the voice signals will be patched to the VHF voice transceiver for relay to and from CDRA.

Astronaut instrumentation.--The television camera will be mounted on the staff orthogonally. It will have a fixed focus lens and require no operating adjustments by the astronaut. The camera control unit, synchronizing signal generator, and video amplifier will be in a back pack cabled to the camera. Necessary operating power will be from the portable generator through LEM relay and LEM mock-up, by cable. Composite video signals from the back-packed video amplifier will be cabled to LEM mock-up for visual monitoring, and to LEM relay for transmission via the microwave link to CDRA.

Staff data sensors will include a sun compass, to use sun angle for geographic reference; a manually positioned clinometer, to read attitudes of geologic features; a two-axis pendulum clinometer to reference staff attitude; and a penetrometer to measure surface bearing strength.

A sun compass consists of a gnomon or vertical rod which casts a shadow on a horizontal azimuth circle. Shadow position, hence sun angle, with reference to a pre-fixed zero, can then be read. Ideally, the shadow position would be auto-reading by means of some photo-sensitive system. Investigations continue into this possibility. One approach

The conventional form of this device is known as a potentiometer. This is a resistance that varies with rotary shaft position. It consists, usually, of an outer resistance element and a concentric shaft connected metal wiper arm. As the shaft rotates, the wiper arm moves along the element, and the resistance as measured between one end of the element and the shaft varies as a function of shaft rotation. In the "Photopot," the wiper arm is replaced by a light beam which falls on a photo-conductive material concentric with and between the resistance element and the shaft. Hence, as the shaft rotates the light beam around the photo-conductor, electrical connection is discretely made between the resistance element and the shaft, providing a variation of resistance with shaft rotation, as in a conventional potentiometer. The modification under investigation will be, in essence, to replace the photo-conductive material with photo-resistive material, and to make the potentiometer into a circular horizontal plane. Thus, illumination will provide resistance, or insulation, and shadow from the gnomon will provide the discrete conductive path, or wiper.

The manually positioned clinometer shaft will be mechanically coupled to a conventional potentiometer for electrical read-out. The two axis pendulum clinometer will be two separate pendulums, free to swing orthogonally to each other.Their separate rotational axes will be mechanically coupled to potentiometers for electrical read-out of staff deviation from local vertical, in two orthogonal planes. This will yield staff attitude, by simple trigonometric reduction.

The penetrometer will be in the base of the staff. The prod, having a known cross-sectional area, will be mechanically coupled to a concentric spring of known constant, compressive or tensile, depending upon mechanical design constraints. The prod will also couple to a linear displacement potentiometer. The maximum resistance deviation from rest will then be a direct linear function of prod area, spring constant, and soil bearing resistance, and can be recorded or displayed in terms of pounds per square inch.

Astronaut instrumentation data handling.--In initial field studies, the resistance readings of the sensors will be transmitted by cable through the LEM mock-up, to the LEM relay for processing and transmission via the microwave voice channel to CDRA. Processing will be in the form of FM/FM telemetry. That is, the resistance change of each sensor will modulate an audio frequency in accordance with industry accepted Inter Range Instrumentation Group (IRIG) specifications. These frequency modulated (FM) audio signals will then be frequency multiplexed (/FM) onto the voice (audio) microwave channel. In the CDRA, the multiplexed signals can be recorded on a single magnetic tape track, or split out by band pass filters, and recorded on separate tracks.

As the requirement for freeing the surface astronaut from "hard" connections to the LEM mock-up (or mission vehicle) approaches, the FM/FM system and its necessary power source will be physically installed in the staff. Because it is planned at this time to command read-out by "button-pushing" on the staff, the telemetry signal, of perhaps one second time duration can be transmitted to the relay over the astro-

in weight, volume and power.

The astronaut's voice radio transmitter-receiver and its power source will ideally be included in the staff, and use the sun compass gnomon as its antenna. A VHF transmitter and power source for the staff television signal will also be required. Initially, this will be in a "back-pack," but investigations into "miniaturizing" the system continue.

Laboratory Investigations Summary

In summary, sufficient information has been acquired to proceed into design and/or procurement of most of the components and systems.

Those not yet firm are still under study and solutions will be obtained in the near future.

Logistics Support

(W. A. Mason)

Introduction

The work effort during this report period has been involved with the acquisition, testing, and installation of electronic equipment to support field operations of the Manned Lunar Exploration Investigations.

Microwave System

Two USGS owned RCA X-band television microwave relay systems, model TVM-1C, were procured to permit field missions activities to be monitored for control from the Command, Data Reception, and Analysis Facility (CDRA) in Flagstaff. These systems are combined to make a two-hop system from the field sites to the CDRA via an already established relay on Mt. Elden near Flagstaff.

This system operates on a frequency of 7.128 gigacycles assigned by the Inter-departmental Radio Allocation Committee (IRAC). The Effective Radiated Power (ERP) is 10 kilowatts and is capable of line-of-sight transmission of over 75 miles, neglecting adverse atmospheric conditions and Fresnel Zone Effects. With the acquisition of a third relay system by MLEI, Hopi Buttes, 85 miles from Flagstaff, will be within the control area of the CDRA. This third system will also provide one-hop relaying in far-field operations between LEM mock-up or mobile laboratory and the field CDRA.

The maintenance and testing of the microwave system is accomplished with specialized test equipment consisting of a video test set, two sweep generators, an R.F. signal generator, a microwave test set, and a volt-ohm-milliammeter. Specialized impedance devices for circuit testing have been designed for this system and will be fabricated as required. Prior to the installation of the microwave relay, a complete test of the microwave system was performed utilizing the test equipment and procedures recommended by the manufacturer.

Mounts fabricated in the Branch of Astrogeology instrument shop were used to affix the receiver, transmitter and antennas to the towers. Trees were cleared to obtain line-of-sight to Bonito Lava Flow. After the alignment of the antennas to transfer maximum signal energy, the microwave link was field tested by the transmission of standard tele-

Bank Building in Flagstaff.

Sound diplexing equipment is currently being installed in the microwave equipment for an FM/FM telemetering channel from the field to the CDRA. This will carry the staff and periscope sensor data.

Radio System

A VHF relay link was established to give voice communication from the field sites to the CDRA through a relay on Mt. Elden. This equipment is installed in 4 field vehicles. Intervehicle communication, at 25 watts, is possible up to 50 miles.

Techniques for providing geologists with "hands free" radio communication from the field are being perfected. This is currently accomplished by continuous keying of a portable transceiver, which allows a geologist, making observations in the field, to transmit his observations to a nearby vehicle for tape recording, thereby eliminating his notebook and pencil, and leaving his hands free to use his field geological instruments. A voice-operated circuit for keying the transmitter to reduce power drain and to eliminate the continuous R.F. carrier is under investigation.

Command, Data Reception and Analysis

Equipment cabinets to house the microwave receiver, radio control unit, television sync stripper, video distribution panel, audio distribution panel, video tape recorder, and video film recorder were purchased and installed in the CDRA.

Lunar Excursion Module (LEM) Mock-up

A KinTel TV camera and a Sony PVJ 303R monitor, acting as a field surveillance system to be used by the LEM astronaut to observe the field astronaut, was received and tested. It was installed in the LEM mock-up to provide the mock-up with field capabilities.

Field Support

Two all-wheel drive, 10-ton vans owned by the Geological Survey have been modified to serve as the field transmission facility between the LEM mock-up or mobile geological laboratory and the CDRA via the Mt. Elden relay and are currently in use for support of the field operations. Other vehicles are one four-wheel drive carryall modified for use as a surveying vehicle, one utility pick-up truck, and two semi-trailer tractors. For future use in support of far-field operations, a semi-trailer van, for use as a mobile CDRA, is being acquired. The equipment used in the fixed CDRA will be installed in this van and eliminate the purchase of duplicate systems. A 1½-ton van is being procured by MLEI for a field relaying facility.

DOCUMENTATION FOR LUNAR FIELD SYSTEMS

(H. Stephens, Project Chief)

Photographic documentation for lunar field systems has a two-fold objective: (1) scientific documentation for detailed analysis of mission operations and tests for Apollo and post-Apollo missions; and (2) documentation of terrains, operations, and tests for dissemination of general information to a broad audience.

Field Operations

Time, Motion, and Information Documentation

Motion picture film records have been made of single and sequenced tasks in geology, geophysics, and surveying performed on a variety of terrains, with standard field techniques and under standard conditions.

Field geologic operations included geologic mapping, section measuring, and sampling operations. Geophysical and surveying operations were mainly concerned with instrument use.

The film records of simple and compound operations performed under normal conditions are available for comparison with operations to be performed under a variety of constraints including planned operations to be performed under suited constraints from a LEM and a mobile geological laboratory.

Test Site Documentation

The geologic and topographic settings of the following test sites have been recorded on 16-mm color film: (1) Bonito and S. P. Crater lava flows in the San Franciscan volcanic field near Flagstaff, Arizona; (2) Meteor Crater; (3) Parts of the Hopi Buttes volcanic field near Winslow, Arizona; (4) Moses Rock diatreme of southeast Utah; and (5) Mono Craters and vicinity, California. Detailed records were made of the geologic and geomorphic relations considered important to mission development, testing, and evaluation.

Laboratory and Library Support

Laboratory Facilities

A mobile field laboratory for the production of film and prints in remote test areas has been completed. This will enable limited review during missions operations testing.

[illegible]

film.

Library Facilities

A library containing the documentary, and the time and motion film footage has been established. Cataloging and indexing of the footage is in process.

The film footage obtained during the reporting period and on file in the library is listed in table 13.

Table 13.--Subject and type of unedited, continuous and intermittently run film for standard geological, geophysical and surveying field operations.

Project and subject matter	Documentary, and time, motion and information footage Color (Feet)	Monochrome (Feet)
Lunar Field Geological Methods - film records of standard geologic tasks used in geologic mapping, sampling and geologic section description by both experienced geologists and inexperienced geologically trained persons.		
1. Experienced geologists describing rock outcrops, using a compass, and collecting and describing samples: Moses Rock, Utah	500	1,200
2. Inexperienced geologically trained persons performing various mapping tasks, sampling by grid method, and describing geologic formations and geomorphology: Moses Rock, Utah	2,500	
3. Inexperienced geologically trained persons describing outcrops, and making compass and tape measurements: Wupatki area northeast of Flagstaff, Arizona	530	
4. Inexperienced geologically trained persons describing geology and measuring slopes with tape and compass: Meteor Crater, Arizona	400	
5. Inexperienced geologically trained persons calibrating pace measurement: Meteor Crater, Arizona	120	

Table 13.--Continued. Subject and type of unedited, continuous and intermittently run film for standard geological, geophysical and surveying field operations.

Project and subject matter	Documentary, and time, motion and information footage: Color (Feet)	Documentary, and time, motion and information footage: Monochrome (Feet)
6. Inexperienced geologically trained persons traversing smooth volcanic ash deposit and rough aa lava flow, describing geology and recording data: Sunset Crater, Arizona	200	
7. Inexperienced geologically trained persons describing geology of volcanic crater and lava flow. Also panoramic views of the crater and surrounding terrain: S. P. Crater, Arizona	160	
8. Inexperienced geologically ... Utah	240	
9. Experienced geologists performing standard geologic mapping tasks: Moses Rock, Utah	250	
10. Experienced geologists measuring and describing geologic sections: Castle Butte area, Hopi Buttes, Arizona	400	
11. Aerial views of Hopi Buttes volcanic field and Meteor Crater, Arizona	400	
12. Details of rock outcrops in test site areas and general views of the terrains.	1,000	
Total	6,700	1,200

Table 13.--Continued. Subject and type of unedited, continuous and intermittently run film for standard geological, geophysical and surveying field operations.

Project and subject matter	Documentary, and time, motion and information footage Color (Feet)	Documentary, and time, motion and information footage Monochrome (Feet)
Lunar Field Geophysical Methods - film records of geophysical instruments.		
1. Operation of portable seismometers, radiometers and magnetometers: Kana-a, Sunset Crater area, Arizona	600	
2. Operation of gravity meter on volcanic ash and rough aa lava flow: Sunset Crater, Arizona	1,200	
3. Operation of seismic equipment: Mono Craters, eastern California	1,300	
Total	3,100	
Lunar Field Surveying Methods - film records of operation of standard field surveying instruments.		
1. Operation of Wild T-2 Theodolite: Bonito Flow, Arizona	969	
2. Operations of K&E Askania Theodolite: Kana-a Flow, Arizona	282	
3. Operation of plane table and alidade: Bonito Flow, Arizona	209	
4. Operations of plane table and alidade		
a) on rough aa lava of Bonito Flow;		915
b) on cinder slope of Kana-a Flow;		708
c) on even ground at McMillan Heights;		642
vicinity Flagstaff, Arizona		

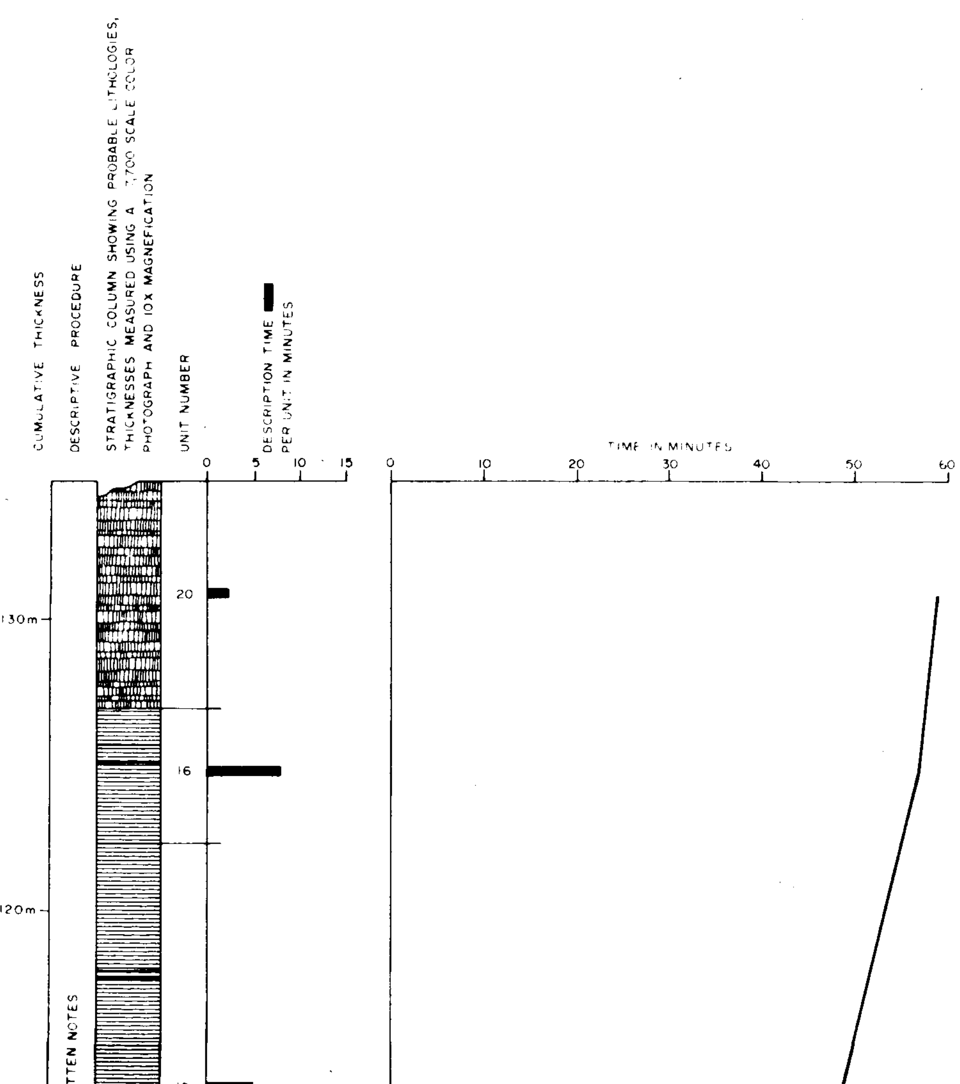
Table 13.--Continued. Subject and type of unedited, continuous and intermittently run film for standard geological, geophysical and surveying field operations.

Project and subject matter	Documentary, and time, motion and information footage Color (Feet)	Monochrome (Feet)
5. Operations of Wild T-2 Theodolite on		
a) rough aa lava of Bonito Flow;		1,693
b) on cinder slope of Kana-a Flow;		693
c) on even ground at McMillan Heights;		849
vicinity Flagstaff, Arizona		
Total	1,460	5,500
Electronic Investigations for Lunar Field Systems - film record of installation of microwave antennae on Mt. Elden near Flagstaff, Arizona	200	
Total	200	

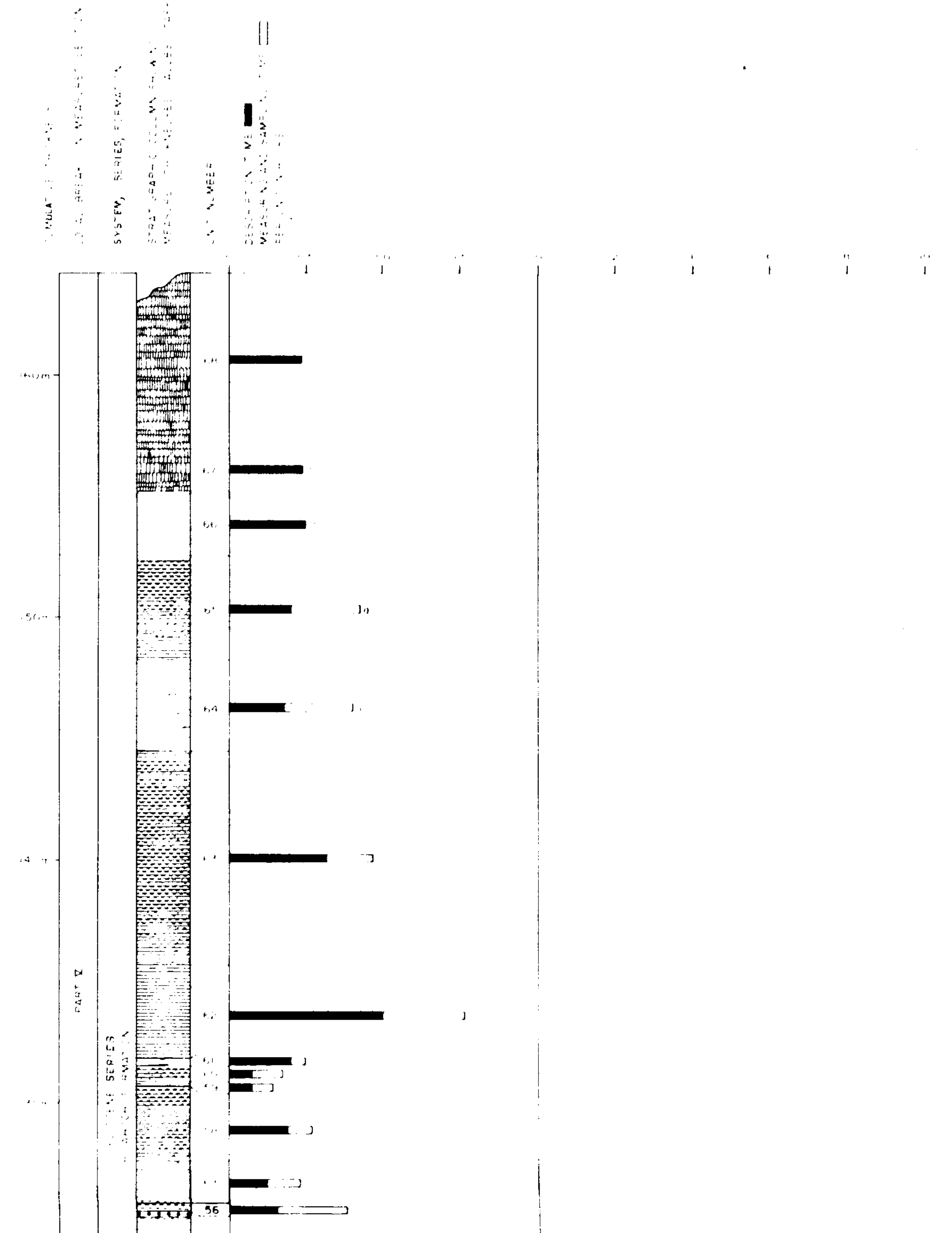
Film Reports

An 11-minute color and sound, 16-mm film entitled, "First Apollo Scientific Mission Simulation" was completed during the first half of fiscal year 1965. Copies were distributed to NASA Headquarters, Marshall Space Flight Center, Huntsville, Alabama and Manned Spacecraft Center, Houston, Texas. Copies are on file in the library in Flagstaff. Film reports have been produced for the geological, geophysical, and surveying field methods.

TEST SECTION A1
REMOTE DESCRIPTION
G. A. Swann

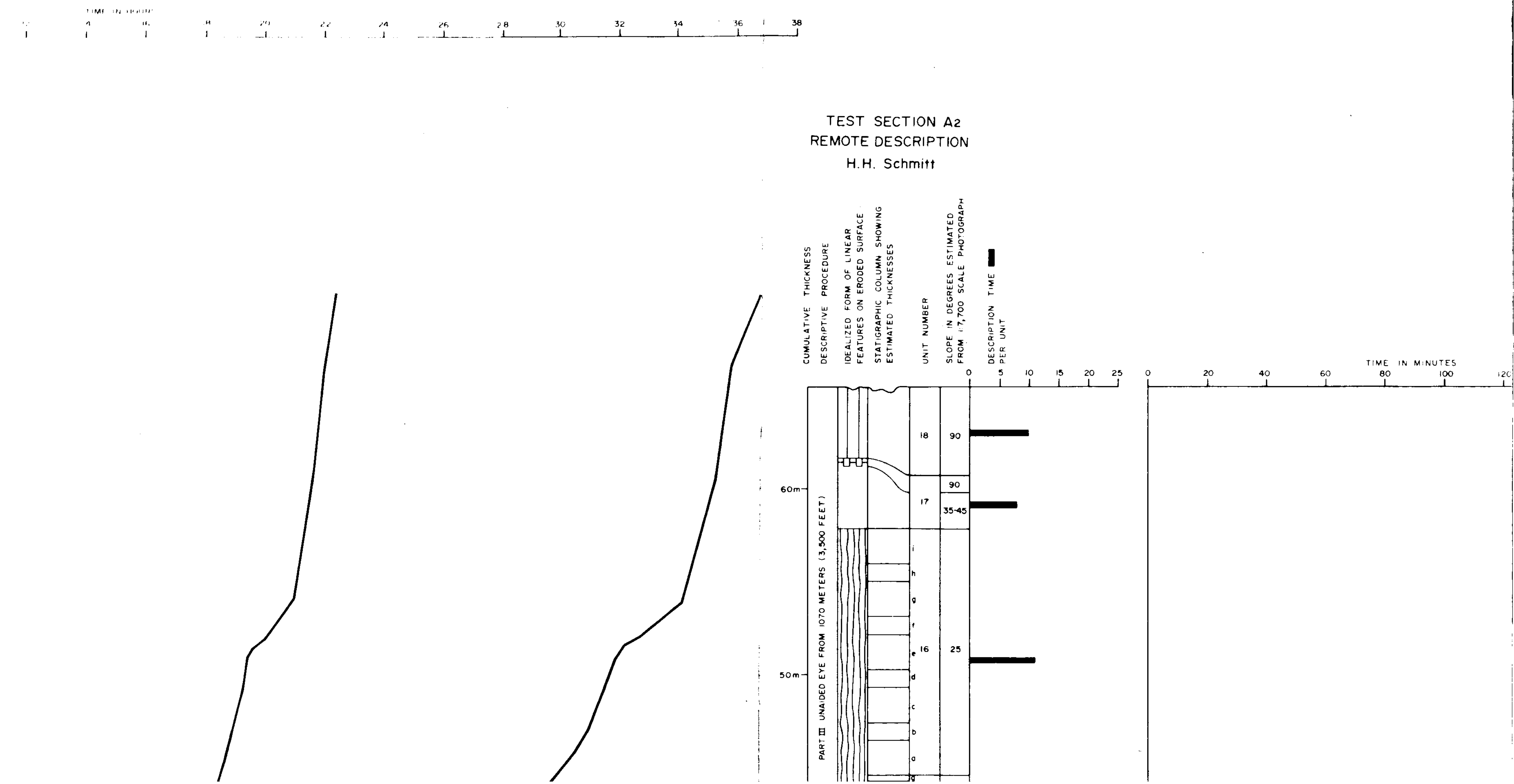


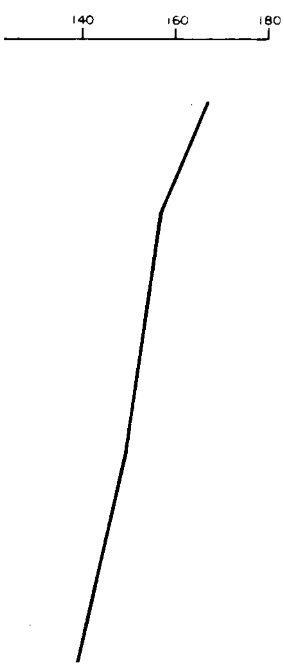
CONTROL SECTION
SECTION A
STANDARD ON-SITE DESCRIPTION
P.J Barosh, J.T. O'Connor and R.P. Christian



2

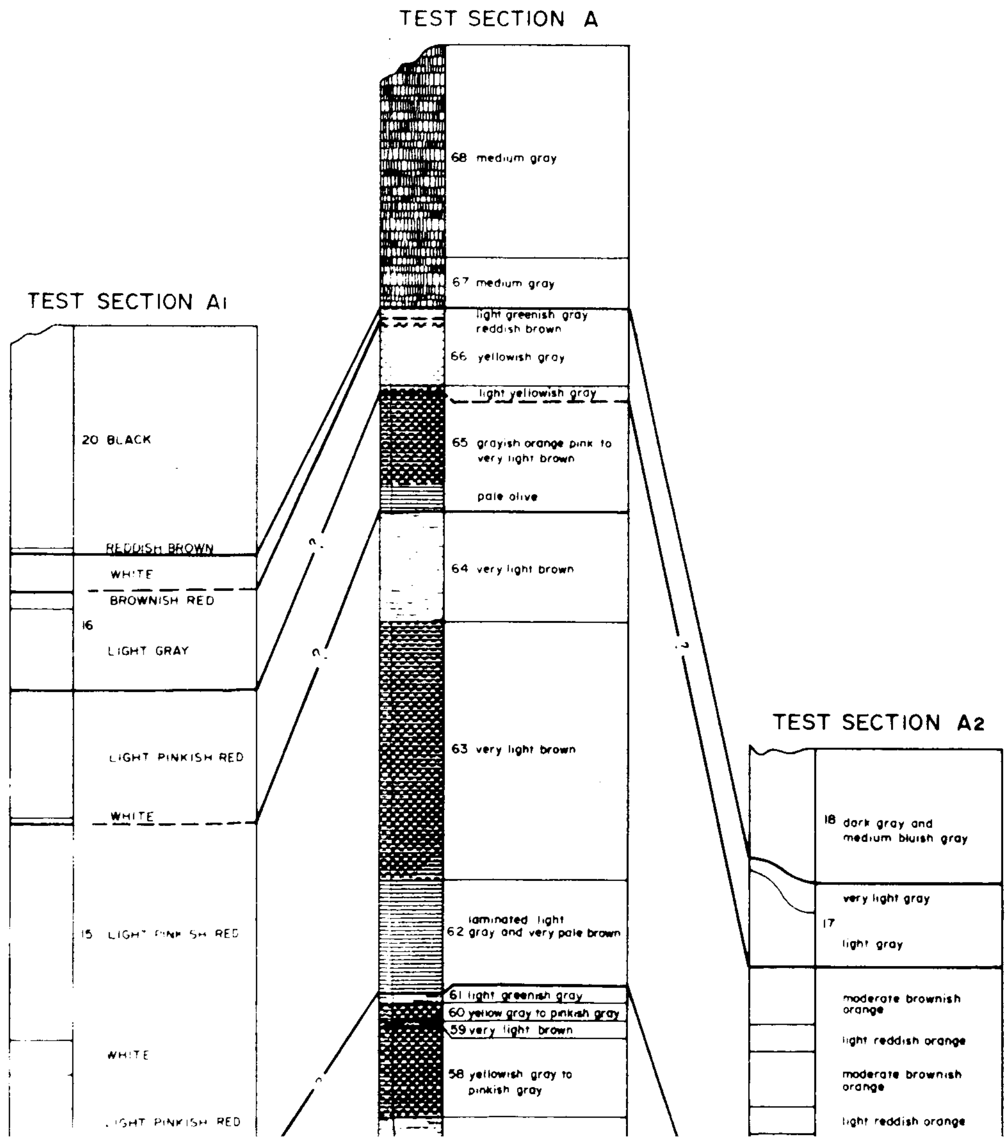
TEST SECTION A2
REMOTE DESCRIPTION
H.H. Schmitt

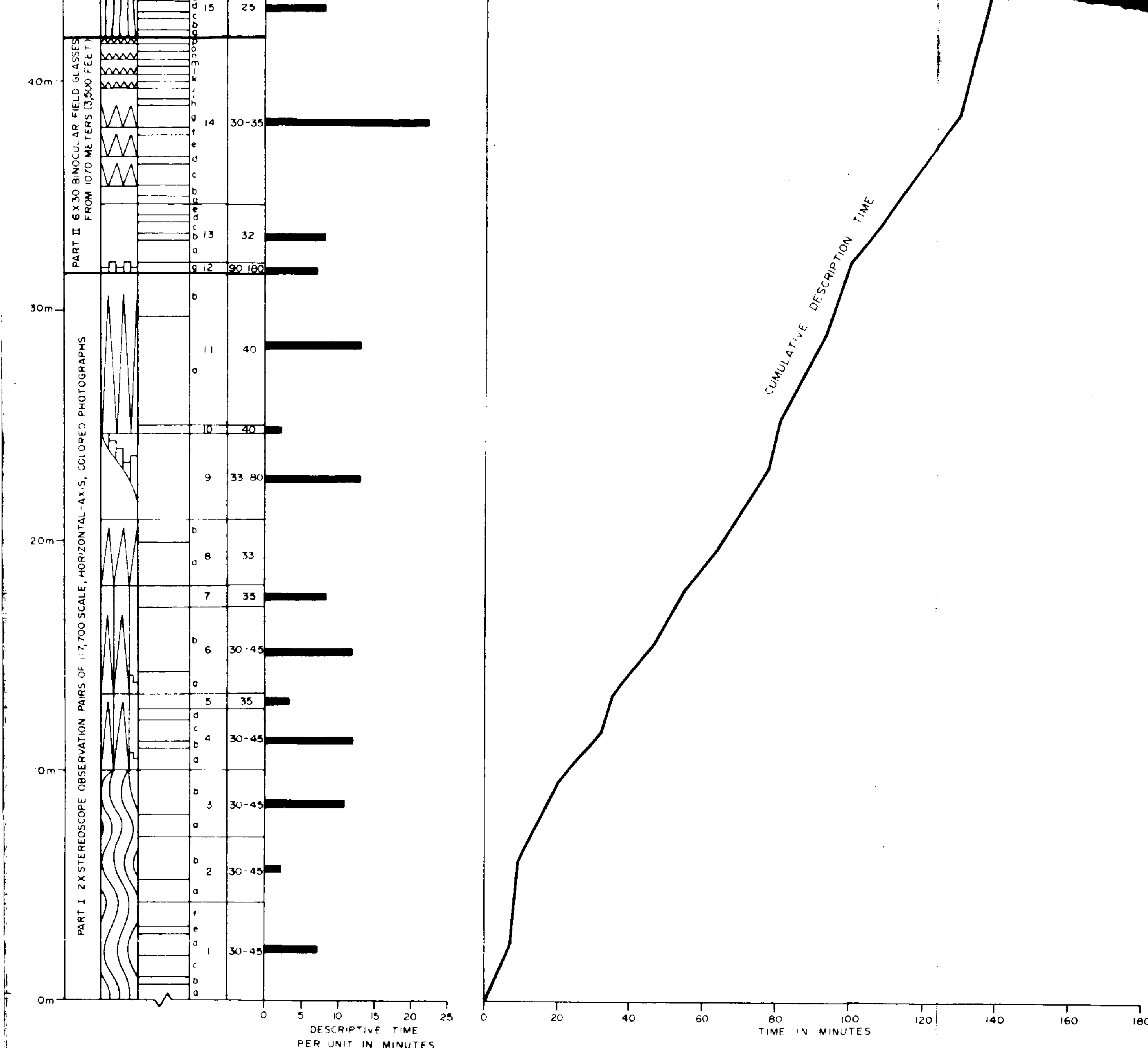


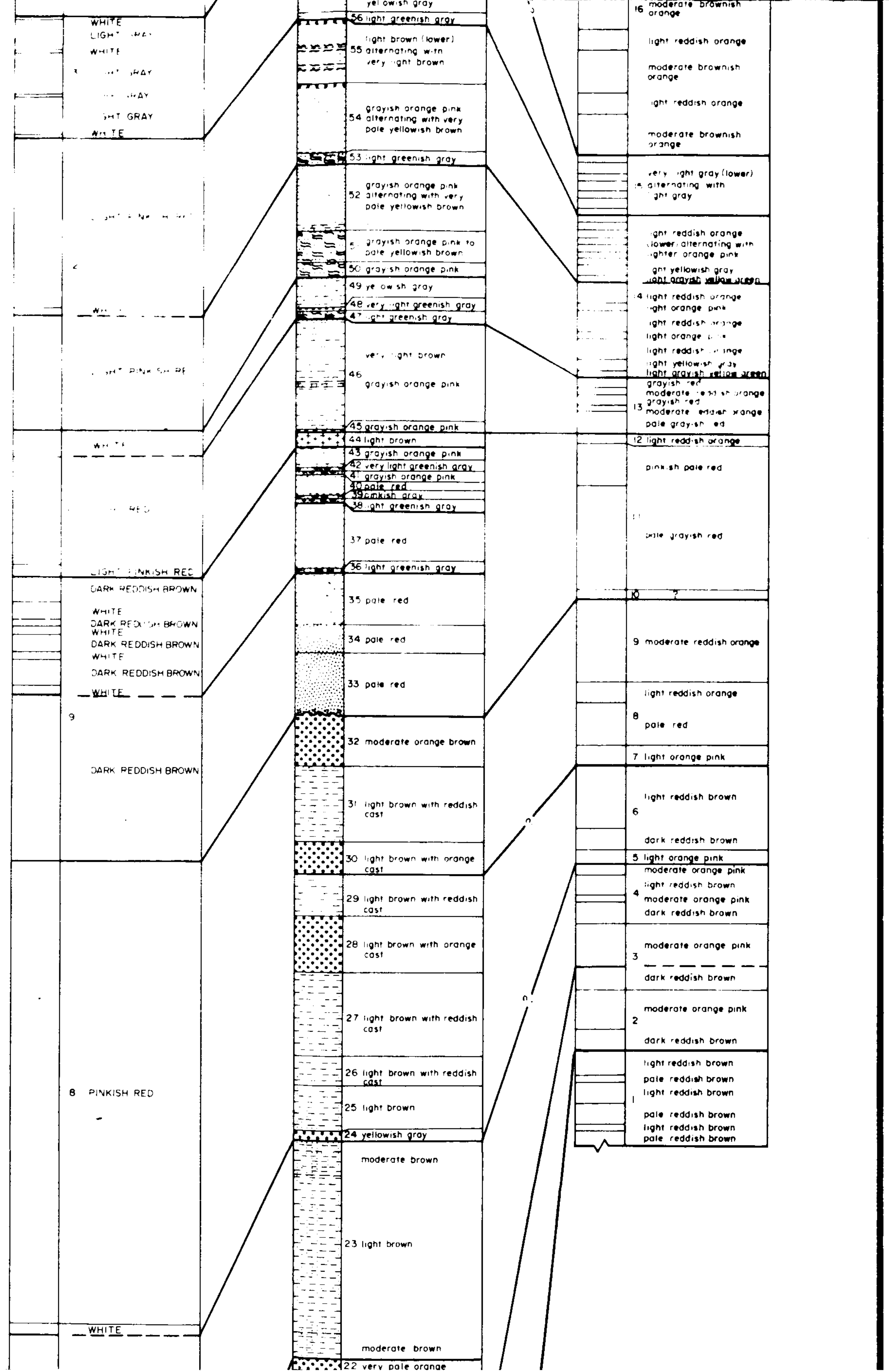


CORRELATION OF TEST SECTIONS WITH CONTROL SECTION SHOWING COLORS OF WEATHERED SURFACES

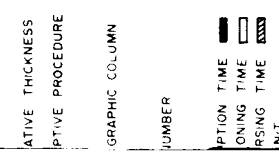
Colors given in Upper Case letters were estimated.
Colors given in Lower Case letters were obtained by comparison with the Rock-Color Chart published by the Geological Society of America (1963).



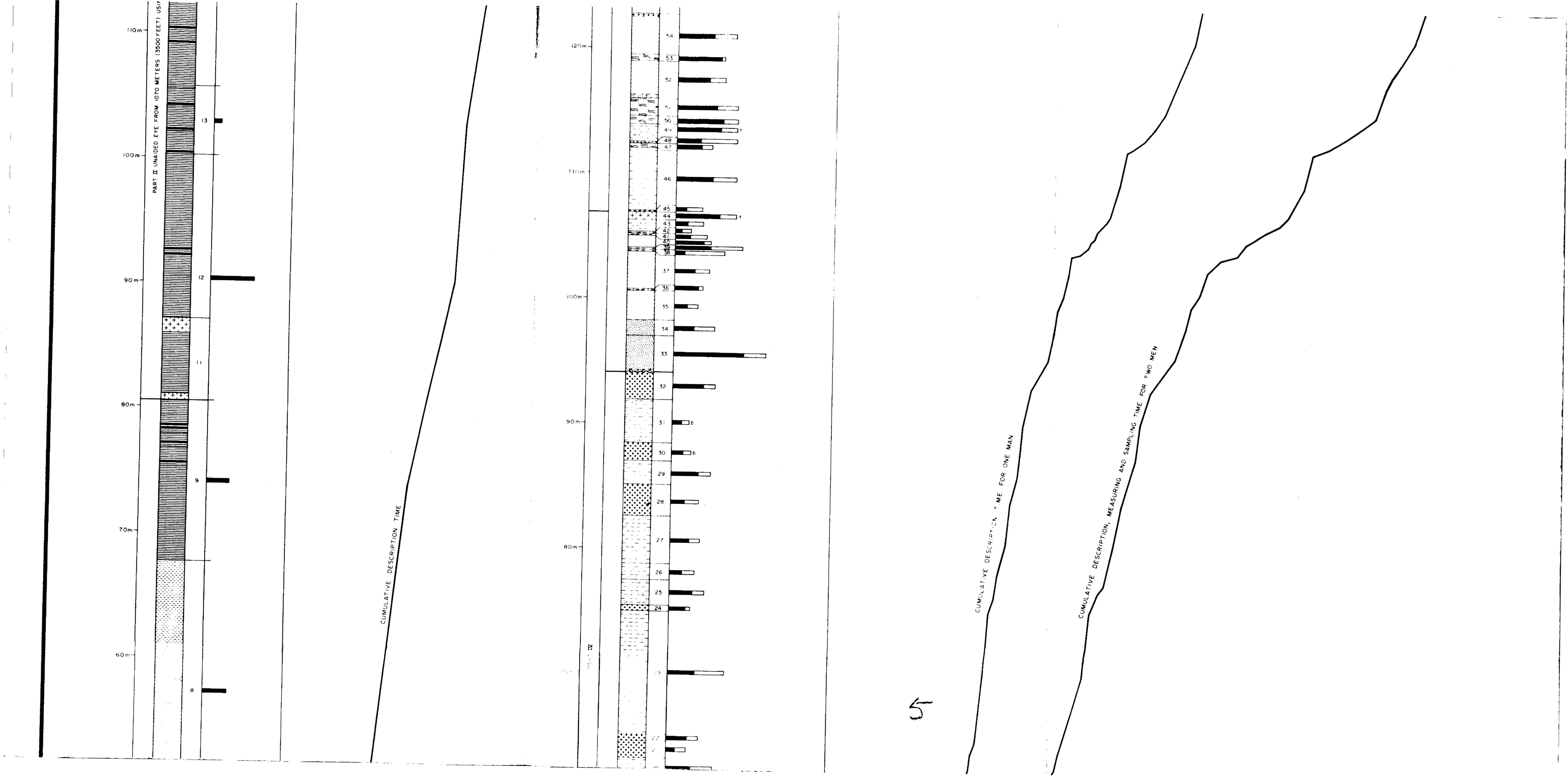


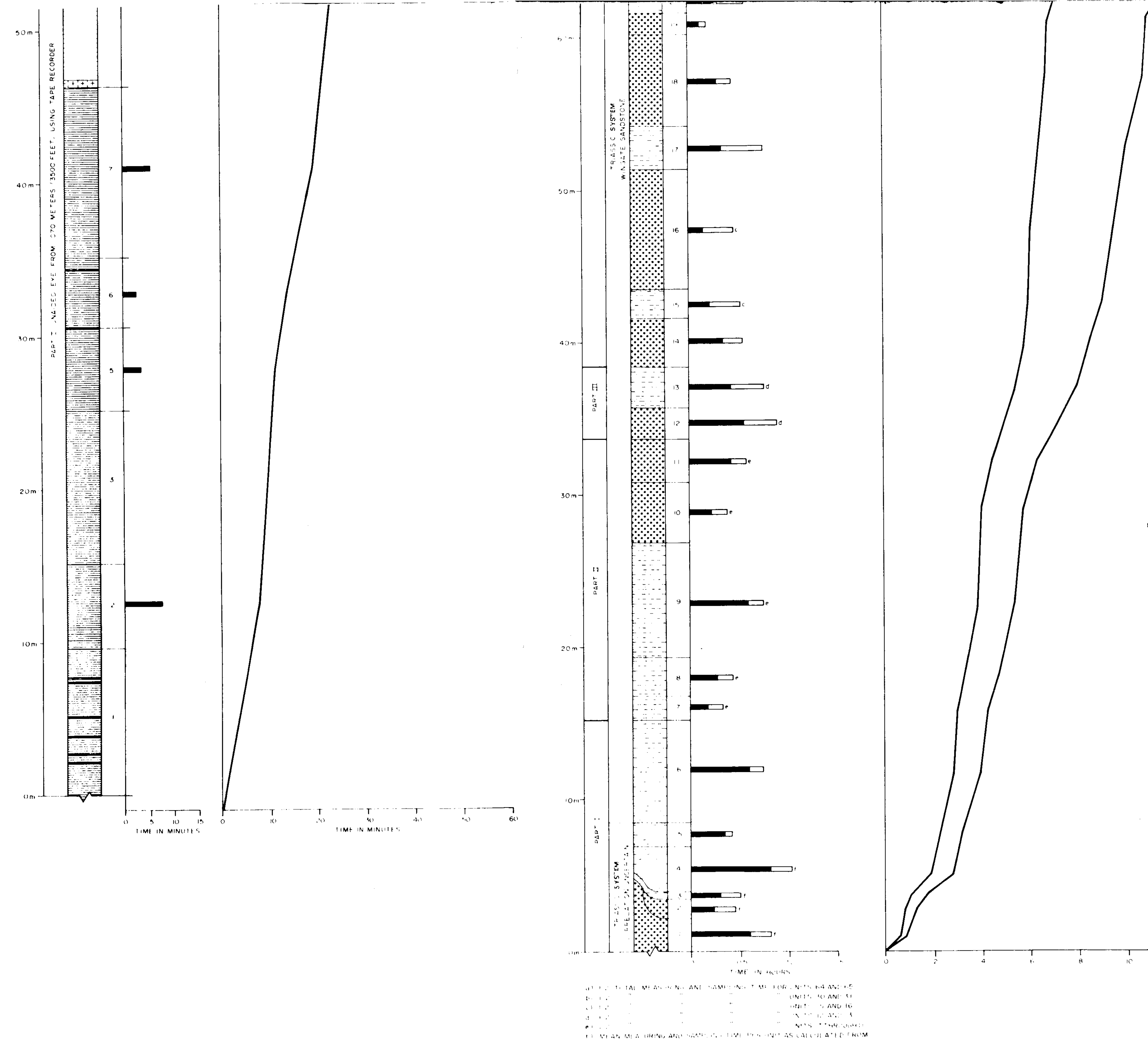


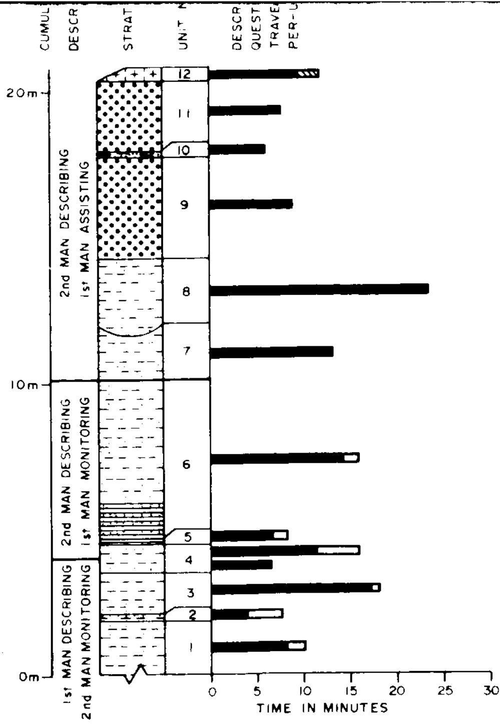
TEST SECTION A3
ON-SITE TEST MISSION
ON PART II OF SECTION A
G.A. Swann and H.H. Schmitt

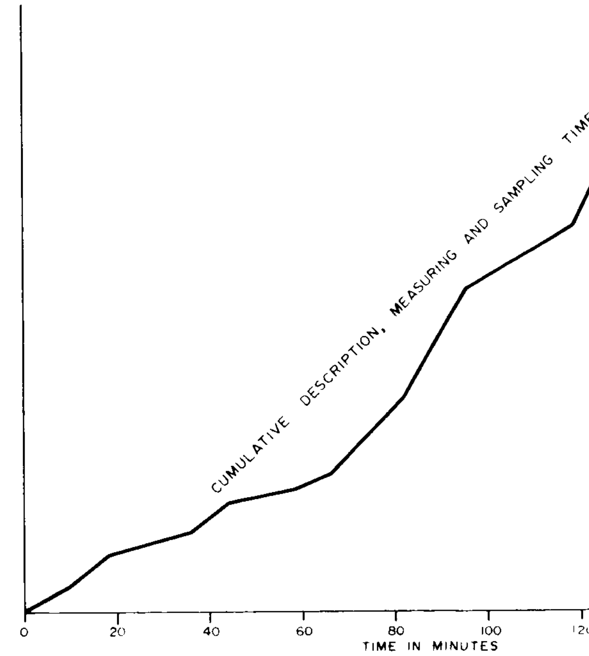


4


PART II UNADED EYE FROM 1070 METERS (3500 FEET) USI
110m
100m
90m
80m
70m
60m
CUMULATIVE DESCRIPTION TIME
120m
110m
100m
90m
80m
CUMULATIVE DESCRIPTION TIME FOR ONE MAN
CUMULATIVE DESCRIPTION, MEASURING AND SAMPLING TIME FOR TWO MEN
5


PART I, NAKED EYE FROM 370 METERS (3500 FEET), USING TAPE RECORDER
TIME IN MINUTES
TIME IN MINUTES
TRIASSIC SYSTEM
WINGATE SANDSTONE
PART III
PART II
PART I
TIME IN HOURS
TOTAL MEASURING AND SAMPLING TIME FOR UNITS 64 AND 65
MEAN MEASURING AND SAMPLING TIME PER UNIT AS CALCULATED FROM





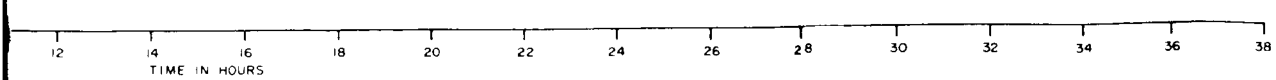


CHART I

LUNAR FIELD GEOLOGICAL METHODS

INVESTIGATION OF SEQUENCED GEOLOGICAL OF

DESCRIPTION, SAMPLING, AND MEASUREMENT OF STRATIGRAPHIC SECTION

LOCATION

West half Sec. 28 and east half Sec. 29, T. 22 N., R. 19 E., mesa bluff 2 miles south-southeast of Castle Butte Trading Post, Hopi Buttes area, Navajo Indian Reservation, Navajo County, Arizona

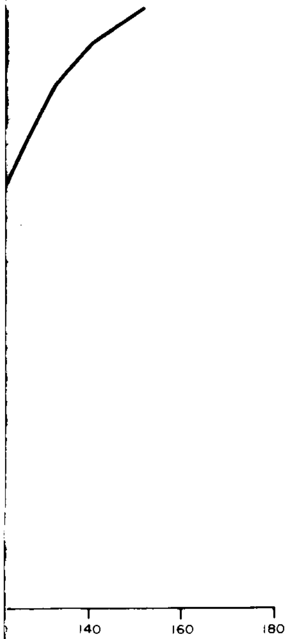
0 5 10m
SCALE IN METERS

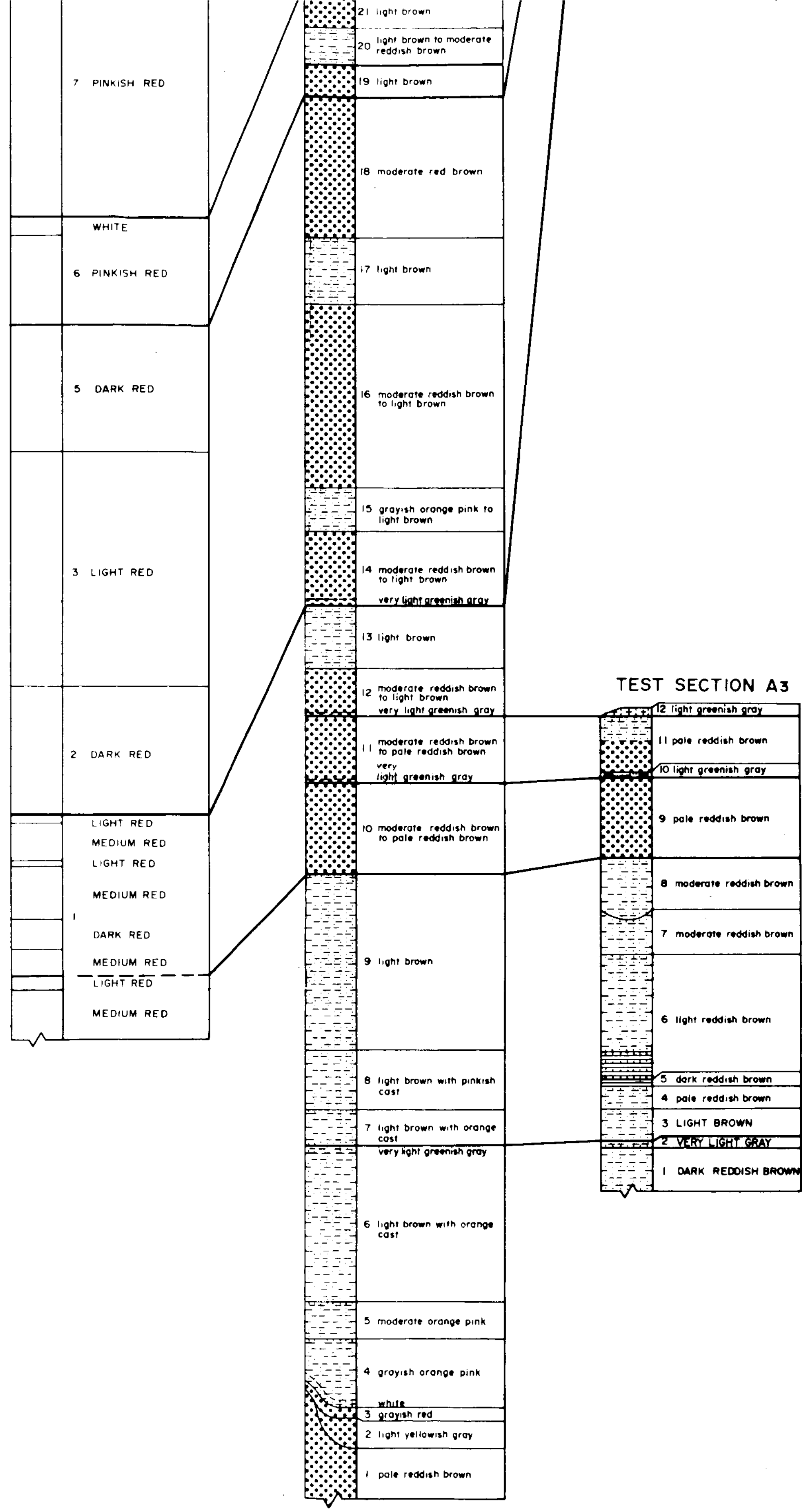
0 25 50ft
SCALE IN FEET

EXPLANATION

- Sandstone
- Silty sandstone
- Siltstone
- Mudstone
- Sandy mudstone
- Mudstone with Siltstone lenses
- Claystone and mudstone
- Tuff
- Basalt
- Pebbles

Chart prepared by: H. H.
G. A. Swann, R. P. Chr





ERATIONS

hmitt, P J Barosh,
tian, J W Van Divier